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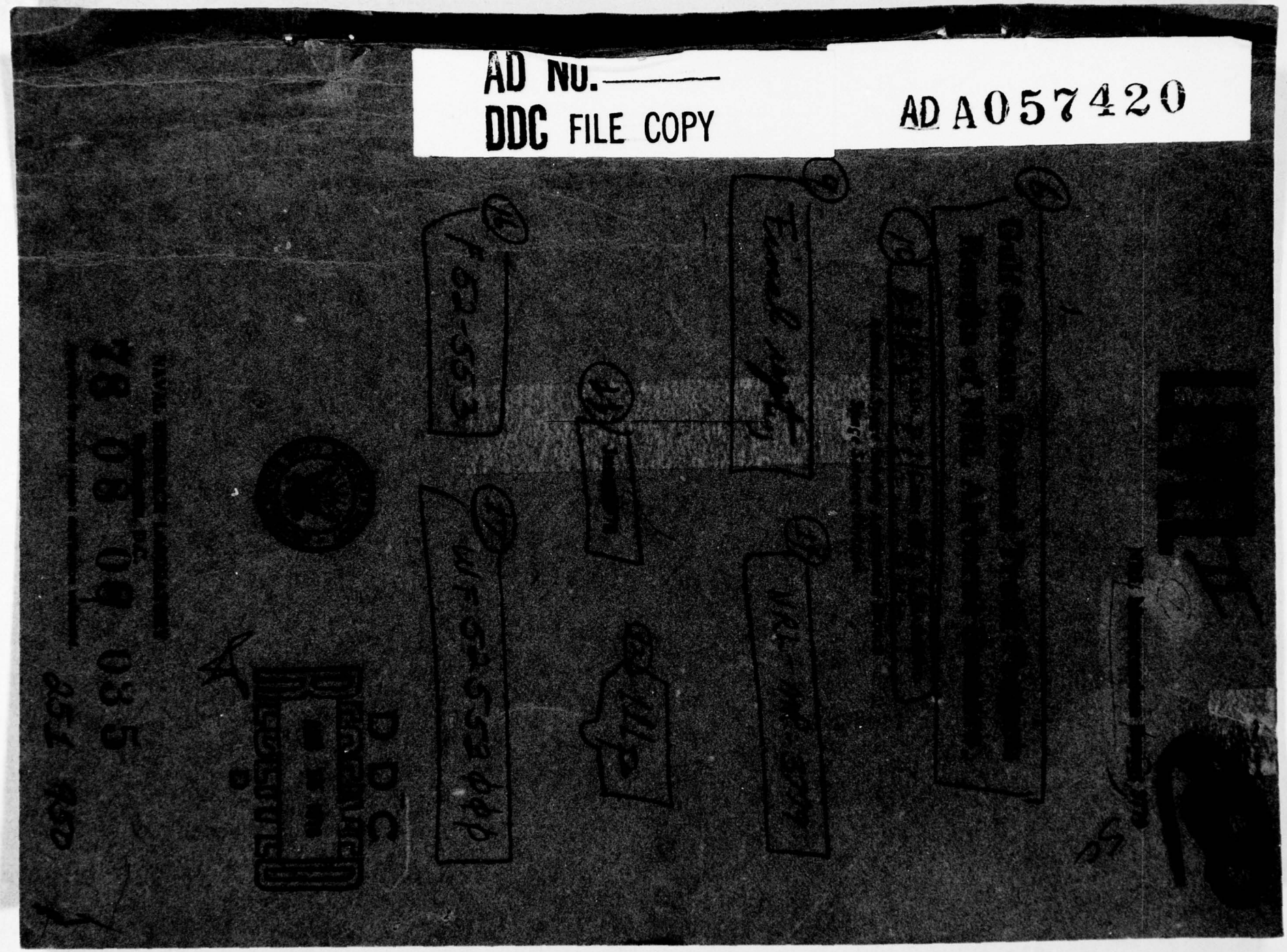

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Wind-wave radar	Spectral aliasing
Precision radiation thermometer	Angular spreading

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of ocean surface measurements by NRL active and passive sensors are summarized. The data set was collected during three flights over the Gulf Stream in the spring of 1976 and coincided with in situ measurements taken from an oceanographic research vessel. The sensors were the NRL high flight radar, NRL wind-wave radar, a laser profilometer and a precision radiation thermometer. The quantities derived include sea state, ocean wave frequency spectra, surface wind speed and sea surface temperature. The remote determinations are found to agree very well with other data
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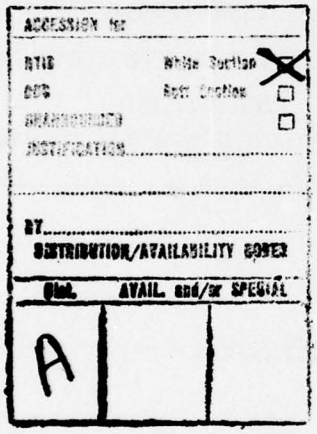
sources. In addition, experimental and theoretical results regarding the effects of ocean wave angular spreading on airborne profilometer determinations of wave frequency spectra are included as well as a detailed description of the data analysis algorithm. The spectral distortion is not severe for track angles within 15 degrees of the wind vector. These indicate that airborne profilometer data is still useful for wind-wave generation studies as long as close attention is given to the track angle relative to the dominate surface wave direction. Also, the proposition of using spectra from various track angles to infer the angular spreading function does not appear promising because the spectra do not show a substantial enough variation with the angular spreading function.



CONTENTS

GULF STREAM GROUND TRUTH PROJECT: RESULTS OF THE NRL AIRBORNE SENSORS

I. INTRODUCTION

During late May and early June of 1976, NASA Wallops Flight Center (WFC) conducted a concerted study of the Gulf Stream. The experiment combined *in situ* measurement of hydrographic and atmospheric parameters with those made by a large variety of airborne remote sensors. The sea truth was furnished by the R.V. Advance II (North Carolina State University). NASA Wallop's C-54 aircraft was instrumented with its AAFE SEASAT-A altimeter, NASA Langley Research Center's AAFE scatterometer (RADSCAT), Naval Research Laboratory's (NRL's) high flight radar, wind-wave radar, a laser profilometer, and a precision radiation thermometer (PRT-5).

The project area was situated due east of WFC in the vicinity of the Gulf Stream. This location was selected for the expressed purposes of (1) testing the satellite altimeter's ability to detect geostrophic current systems, (2) comparing the surface temperature signature to the actual current location, and (3) checking the airborne altimeter's sensitivity to rapid changes in sea state, such spatial inhomogeneities in sea state should exist there because of strong wave-current interactions (Chen and Bey, 1977). Results relevant to (1) have indicated a positive capability which have been reported by Leitao, *et al.* (1977). In addition to these goals, the experiment afforded an excellent opportunity to resolve some fundamental questions about a profilometer's ability to obtain correct

Note: Manuscript submitted April 26, 1978.

wave-frequency spectra as well as information on the wave field's directional properties. NRL was also responsible for the analysis of the precision radiation temperature data. The results presented herein are only those derived by the NRL-sponsored sensors and appropriate comparisons are made with those of other devices.

II. EXPERIMENT PLAN

Because the aircraft housed several instruments, each with its own particular requirements, a rather complicated flight plan was devised by the participants. Figure II-1 is a depiction of the general scheme and the sensors to be operated at each altitude. A 3048 m altitude was selected because it is the ceiling for flights without supplemental oxygen and it is necessary to fly as high as possible for the operation of altimeters using waveform analysis as is shown by Walsh (1977). Star patterns of different geometries were incorporated at the 1524 m and 305 m levels. At 1524 m, the RADSCAT was flown upwind, downwind and at 45° to the wind. Figure II-2 shows the proposed pattern at 305 m where the NRL wind-wave radar and the laser profilometer were operated. Two sets of such patterns were included, one on each side of the Gulf Stream front with continuous data to be collected by all designated sensors during the 3048 m transit.

Three missions (5/27, 6/2, 6/4) were completed during a two week period. The position of the frontal system was supplied prior to each flight by the Advance II, which continuously maintained stations along the track between the coordinates (36°28'N, 72°30"W) and (37°28.5'N, 72°30'W) during this time interval. Earlier flights included an initial systems check-out and later another (5/26) that was scrubbed due to a malfunction in the Inertial Navigation System (INS).

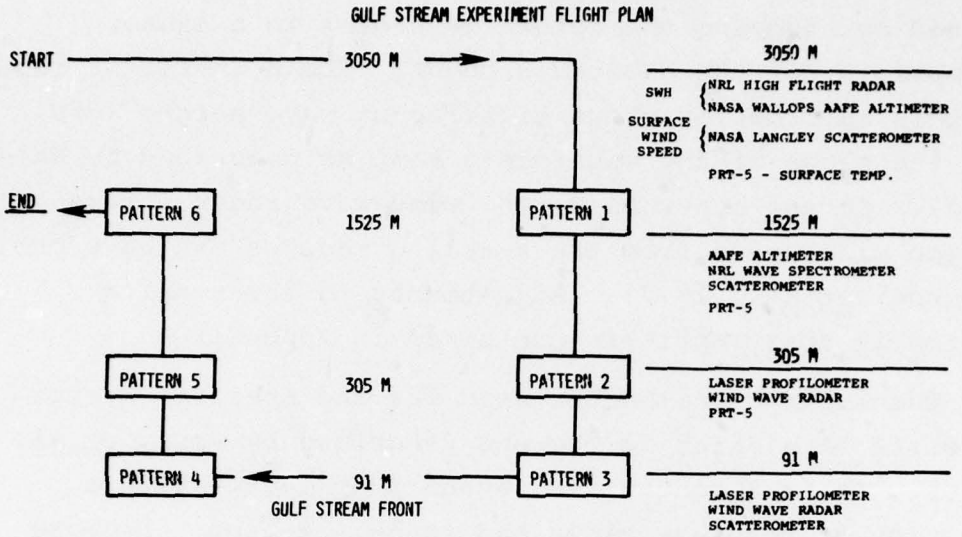


Fig. II-1 — General flight scheme

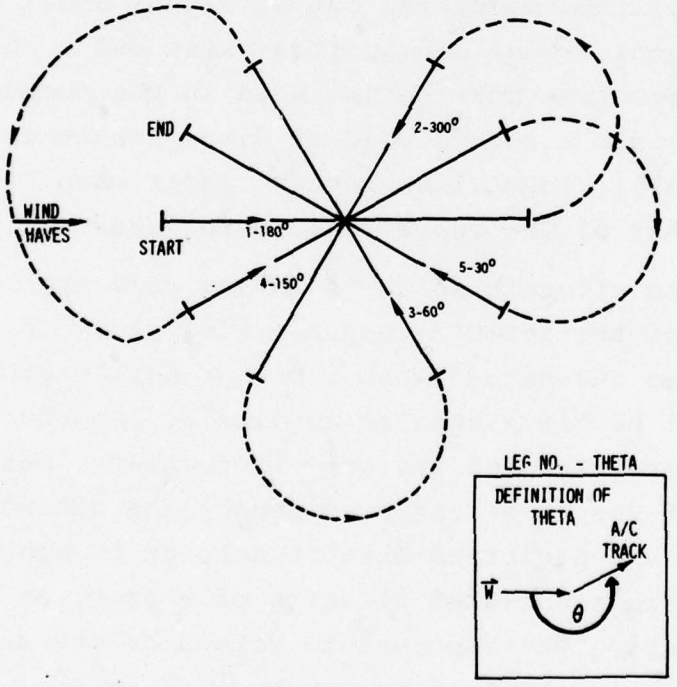


Fig. II-2 — Star pattern at 305 meters

III. INSTRUMENTATION

NRL's microwave devices mentioned above are nadir-looking short pulse radars, the results from which are derived by studying the return waveforms in a manner appropriate for the desired product. The high-flight radar provides information about significant wave height (SWH) from the slope of the waveform's ramp as described by Walsh (1974). On the other hand, the wind-wave radar infers surface wind speed from the trailing edge of the waveform (Hammond, et al., 1977). Adjustments to the results printed in that paper are contained in Appendix A.

The laser profilometer used was the Spectra-Physics Geodolite 3A similar to the one described by Ross, et al. (1970). It is a continuous output (CW) device with a selection of response times and range settings. Because range is measured by comparing the phase shift between the returning amplitude-modulated output signal and a similar reference signal, range ambiguities exist and a phase shift detection subroutine must be included in the computer software to yield a record void of discontinuities. These are rather easily identified because their magnitude is similar to that of the range scale being used.

Since the aircraft (A/C) is moving at a high velocity, the effects of the laser's response time should be investigated so as to understand what apparent wavelengths being profiled will be diminished in amplitude. Appendix B includes a derivation of the cut-off frequency based on the definition of response time provided by the operation manual. Because digitized data is subject to Nyguist folding and the associated aliasing of energy, an additional calculation using the appropriate values of the sampling frequency (f_s) and cut-off frequency (f_c) is included. Additionally, the folding frequency (45 Hz) is high enough

in this instance to ensure that little energy would be found in the corresponding portion of the wave spectra.

The laser was calibrated prior to the experiment and was found to be working properly on all range settings (10 ft., 20 ft., 40 ft., and 100 ft.). Table 1 gives the conversion coefficients for these ranges subject to the output voltage options ($\pm$1.4 V, 0-10V). It should be noted that the analog-to-digital converter used on board the aircraft had a $\pm$1.0 V maximum input and voltage dividers were inserted wherever necessary to accommodate this restriction and these modify the laser calibration constants. Figure III-2 shows the entire recording system.

Figure III-1 indicates that pitch, roll, and vertical acceleration were monitored. These quantities were supplied by the Inertia Navigation System (INS), but only vertical acceleration was utilized in the data analysis. Our flights occurred during periods of relatively quiescent atmospheric conditions, therefore we did not feel that pitch or roll would significantly affect the profilometer ranging. A simple calculation provides an estimate of the ranging error (Δz) induced by these two motions.

$$\Delta z = z(\sec \phi - 1), \tag{1}$$

where z is the A/C altitude and ϕ is the value of the pitch or roll angle. Equation (1) refers to a plane surface. Closer examination reveals that any attempt to correct these errors based on (1) may not improve the result. The beam's horizontal excursion (Δx) from nadir is given by (2),

$$\Delta x = z \tan \phi \, . \tag{2}$$

For example, if $\phi = 3°$ and $z = 305$ m, Δx would equal 16 m, a distance sufficiently far away from nadir to make a range correction for a random ocean surface rather questionable.

Table 1 — Laser Conversion Factors

RANGE (FT)	LASER PEAK-TO-PEAK OUTPUT (V)	CONVERSION FACTOR (FT/mv) - (m/mv)	MODIFIED FACTOR (FT/mv) - (m/mv)
10	±1.4 0-10	0.00357 - 0.00109 0.001 - 0.000305	0.005 - 0.00152
20	±1.4 0-10	0.00714 - 0.00218 0.002 - 0.000610	0.010 - 0.00305
40	±1.4 0-10	0.0143 - 0.00436 0.004 - 0.00122	0.020 - 0.00610
100	±1.4 0-10	0.0357 - 0.0109 0.010 - 0.00305	0.050 - 0.0152

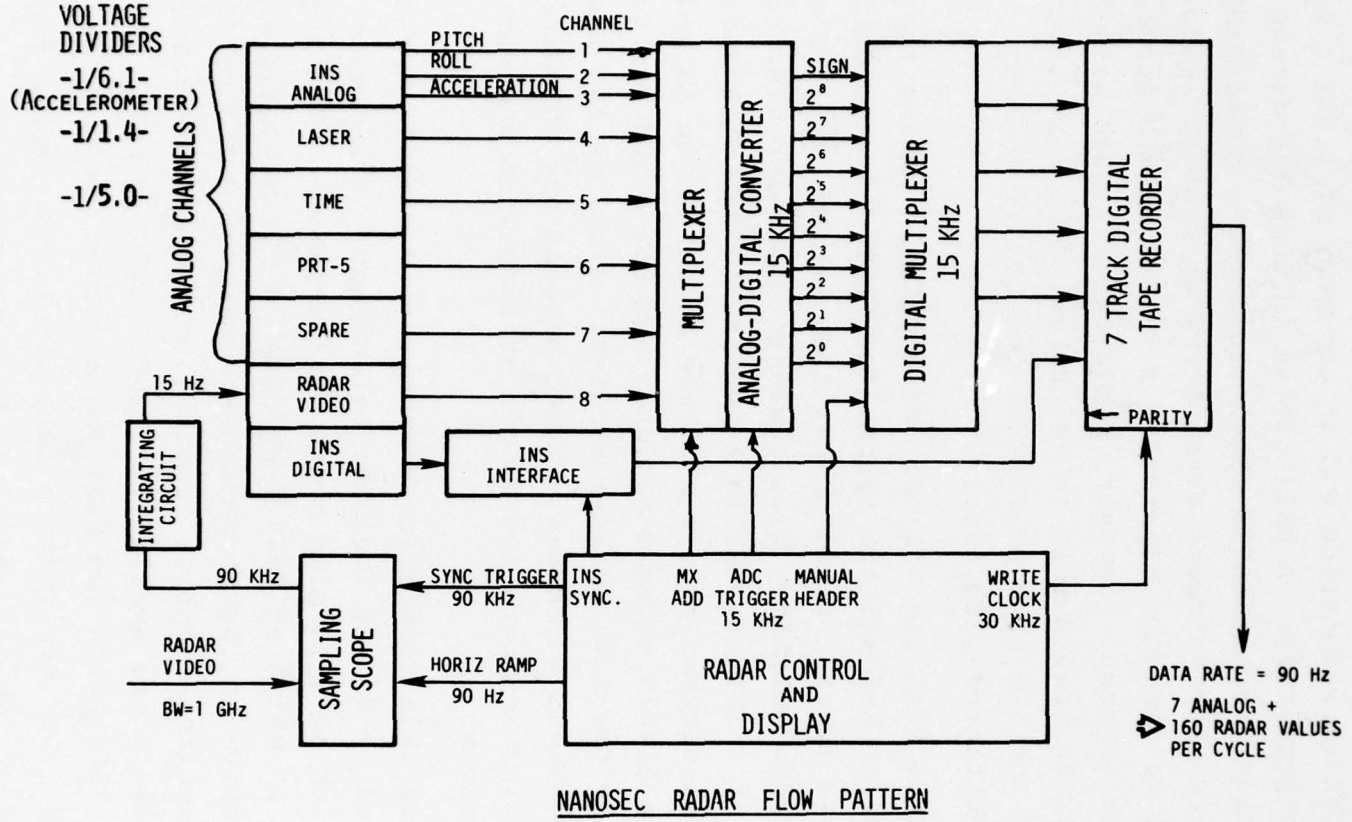


Fig. III—1 — Data recording system

Thus, one has little recourse but to accept this limitation on the profilometer's accuracy.

The accelerometer in the Wallops INS (a Bendix LTN 51) has a specified resolution and an accuracy of 0.001 g and 0.01 g, respectively. A malfunction in this INS during the 5/26/76 flight necessitated the borrowing of another INS (LTN 72) from the Patuxent Naval Air Test Center. Unfortunately the calibration constant for that system's accelerometer was unknown. However, conversations with personnel from Bendix indicated that it is probably the same instrument as in the LTN 51 even through the LTN 72 is not normally outfitted with one.

Problems with the Wallops INS continued during the 6/2/76 mission and all the tracks for that day were derived from LORAN-A fixes. Large disparities between the INS and LORAN-A tracks existed. This presents a problem since a knowledge of θ (Figure II-2) is essential to the data reduction. Loran-derived values of θ are contained in Appendix C. Data on 6/4/76 offered a higher sea state and was quite adequate for the wave spectra studies. Also, on the last flight, excellent agreement existed between the INS-derived wind direction and both the ship's surface wind and dominant wave directions.

The precision radiation therometer is a model PRT-5 manufactured by Barnes Engineering Company. The device operates with an 8-14 micron window (infrared). The field of view is 2° which at 3048 m produces a 106 m spot diameter. It is operative in the temperature domain of -20°C to 75°C, but has a nonlinear output response to temperature. Three range intervals are available, (-20°C, 15°C), (10°C, 45°C) and (40°C, 75°C) with two full scale output options, 0-1 V and 0-50 MV. Our application fell within the medium range. Examination of Table 2 indicates that the output is

Table 2 — PRT—5 Calibration

TEMPERATURE (^{o}C)	% FULL SCALE OUTPUT	
10	0.000	
11	2.430	
12	4.886	
13	7.366	
14	9.871	
15	12.401	INTERVAL USED IN EQUATION 3
16	14.956	
17	17.535	
18	20.140	
19	22.770	
20	25.425	
21	28.105	
22	30.810	
23	33.540	
24	36.295	
25	39.075	
26	41.881	
27	44.712	
28	47.568	
29	50.449	
30	53.356	
31	56.288	
32	59.245	
33	62.228	
34	65.236	
35	68.269	
36	71.328	
37	74.412	
38	77.522	
39	80.656	
40	83.817	
41	87.003	
42	90.214	
43	93.450	
44	96.712	
45	100.000	

particularly nonlinear near the high temperature end of that range. The data in Table 2 was taken from the operation manual. For this reason a temperature subrange (15°C, 27°C), was selected based on Figures IV-1 and IV-2 and and a calibration constant was calculated to be 0.371°C/% full scale over that interval. The 0-1 V output was used during the Gulf Stream flights and since the recording system registers MV values, the equation for temperature (°C) becomes

$$T = 15° + (X - 124.0)\ (0.0371), \qquad (3)$$

where X is the value recorded.

Operation in cold environments (below -20°C) may cause the apparatus to provide false values. A precision thermistor Bolometer mounted in a tightly controlled reference temperature cavity is used in stabilizing the system. If the cavity temperature is allowed to drop below the design value, incorrect readings will result. Also the wind chill factor can elevate the minimum ambient operating temperature.

IV. ENVIRONMENTAL DATA

When attempting to draw conclusions pertaining to ocean wave development, environmental history is of primary importance. A large number of factors are involved in the physics of this phenomenon and the technique used here requires additional information. Consequently, we have placed much emphasis on the collection of these physical parameters and were assisted in doing so by several different agencies. The data gathered included surface weather charts from the National Weather Service (NWS), Gulf Stream frontal analysis from the Naval Oceanographic Office (NOO), SWH analysis from Fleet Numerical Weather Central (FNWC) and additional supporting data taken on the Advance II. Of fundamental importance are the surface wind speed, direction, duration

and fetch, air-sea temperature difference, estimated SWH and the direction of the dominant wave component. Other factors such as the curvature of the wind field also enter into SWH analyses. Since we did have at least two sources of SWH, the ship and FNWC, no attempt to implement a wave height analyses scheme based on the above mentioned data was made for the area concerned. Nonetheless, that additional data is included in the figures discussed below.

The frontal analysis charts indicate that the flight patterns were flown directly over the Gulf Stream and that the location of the current was stationary in the test area during the project period. The experiment area is indicated by the two ship survey lines, the first of which was completed prior to the flights. The in situ measurements plotted along the ship's track are in excellent agreement with the NOO data derived from satellite IR determinations (see Figures IV-1 and IV-2).

May 27: (Figures IV-3a to 3d)

The general weather situation at the beginning of the day (0000 GMT) was as follows: the experiment area was under the influence of a weak high pressure cell (1022 mb) which was the eastern portion of a high pressure ridge extending from the Great Lakes region southeastward through the mid-Atlantic states. The resulting isobaric pattern was in a NE-SW orientation over the area of interest. An atmospheric surface wave formed at that time approximately 1055 km due east of the area along a stationary front which extended southwestward through central Florida. During the next 24 hours, this wave developed into a weak low pressure system, intensified, and moved rapidly towards the northeast away from the test area. As this low migrated into the North Atlantic, the high pressure ridge extended further seaward from the Virginia and Carolina coasts causing the geostrophic

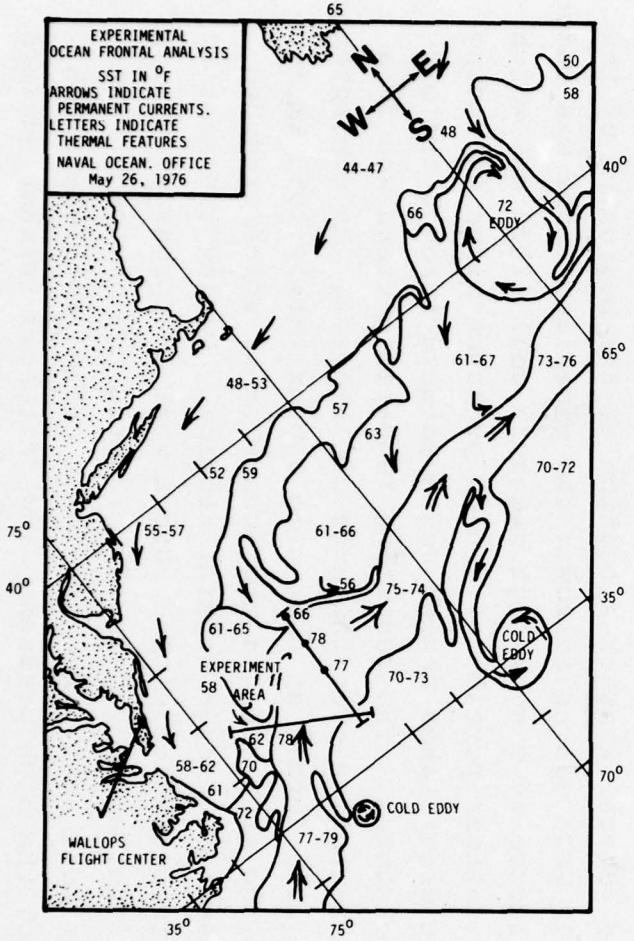


Fig. IV—1 — NOO Gulf Stream frontal analysis, 5/27/76

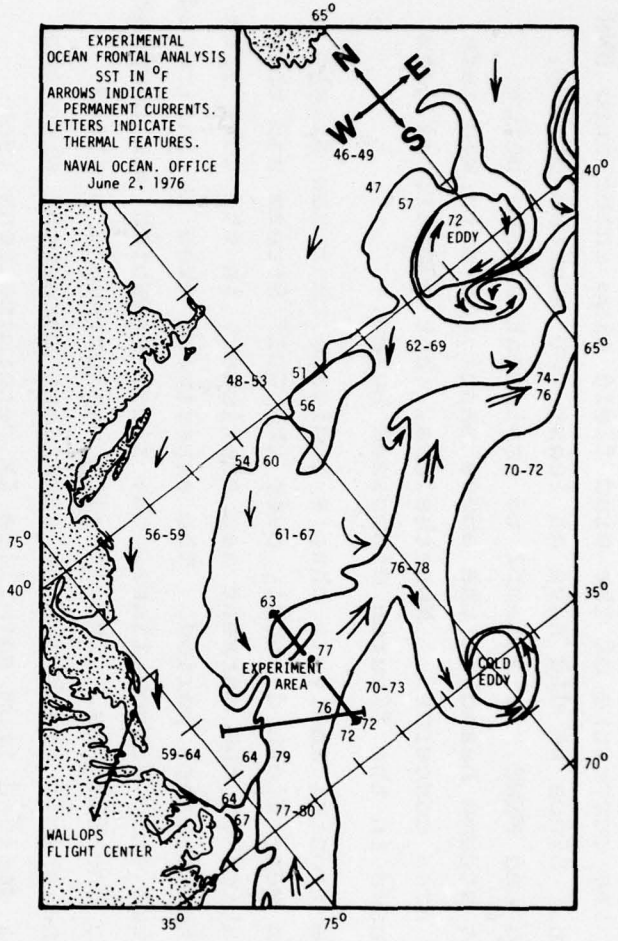


Fig. IV—2 — NOO Gulf Stream frontal analysis, 6/2/76

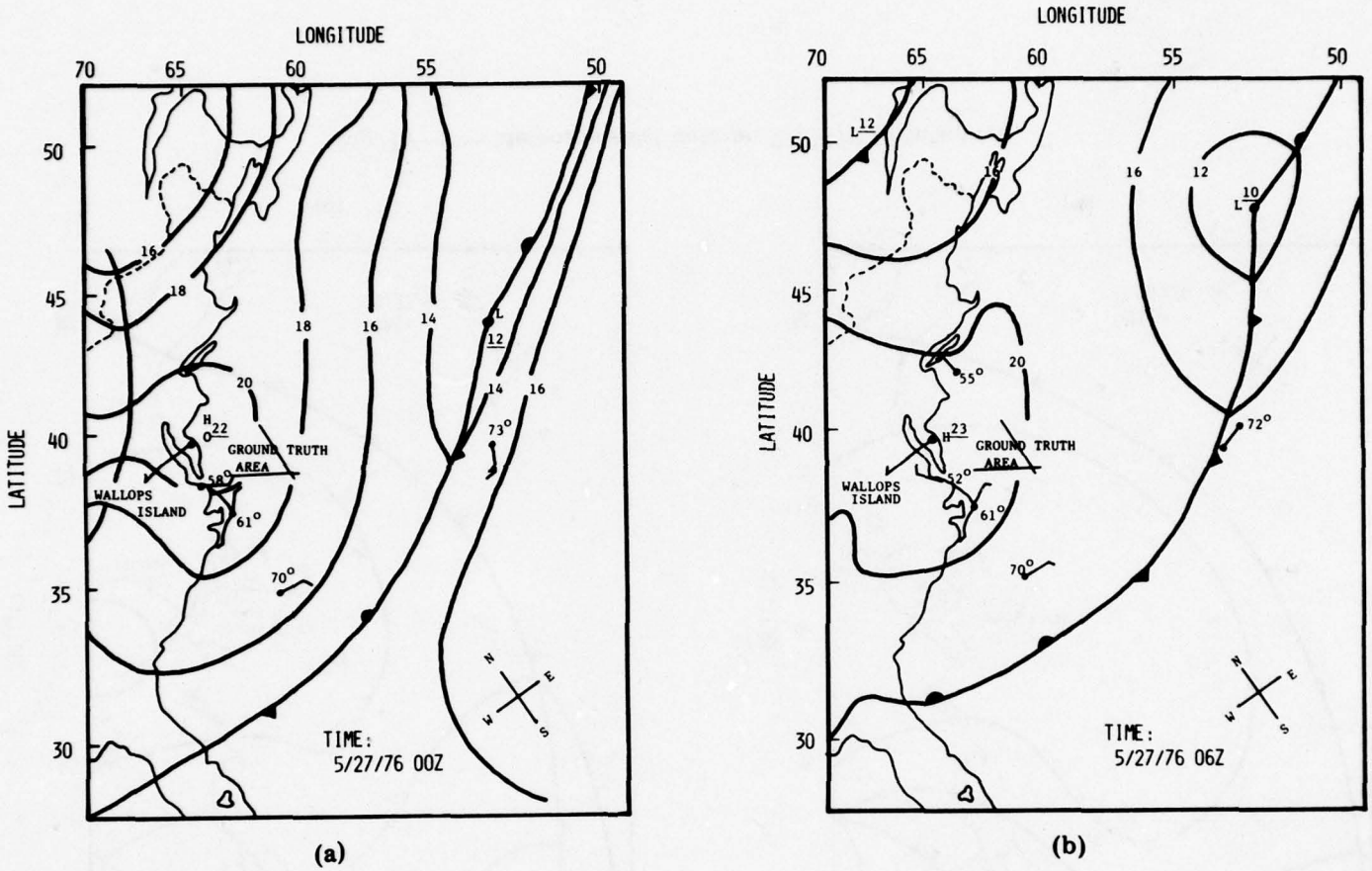
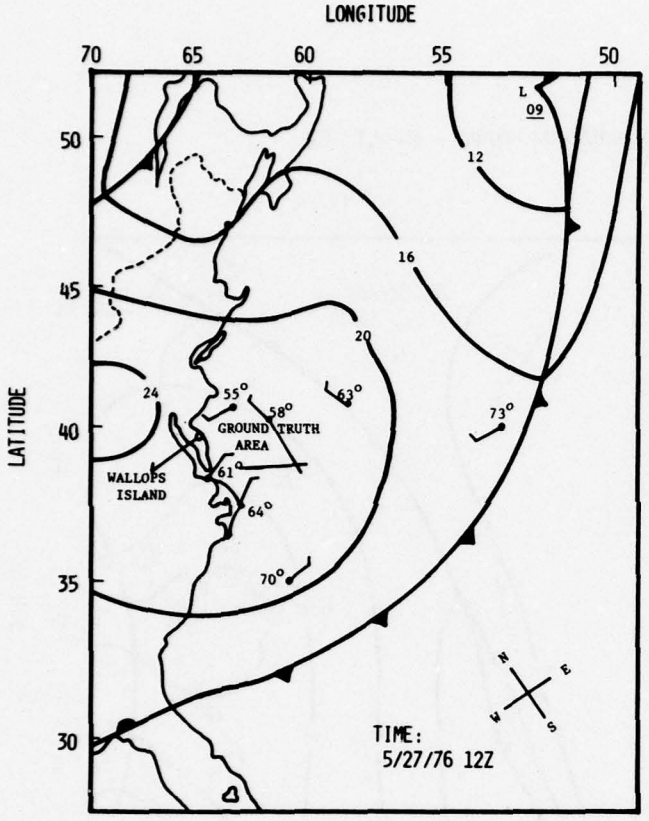


Fig. IV—3 — Meteorological data on 5/27/76 (Continues)



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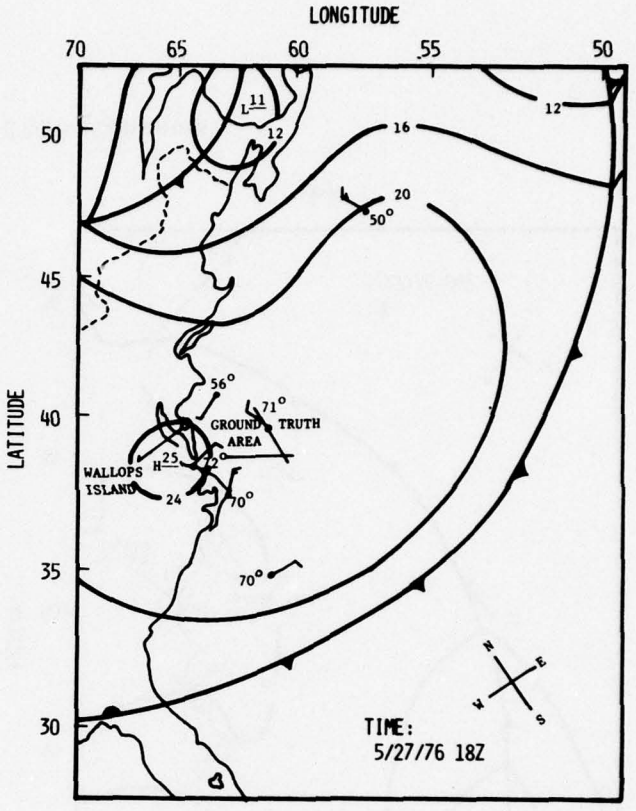


(d)

Fig. IV—3 — Meteorological data on 5/27/76 (Continued)

flow over the test area to rotate to a more N to NNE direction by 2400 GMT. With the weather following such a pattern, fetch and duration estimation is rather subjective. Indeed, swell propagating at a large angle to the wind direction (ship report) that afternoon definitely confused the issue of spectral development and therefore spectral analysis was not routinely made.

June 2: (Figures IV-4a to 4d)

Initially, a southbound cold front extended in an east-west direction just north of the 40° parallel. Also, a surface wave which had formed 30 hours earlier and had been located along a stationary front (over central Missouri) was now centered over western Virginia. It resided along the northern extension of the stationary front approximately 110 km south of the advancing cold front. At this time, the test area was experiencing a southwesterly flow and was situated beneath the western portion of a high pressure system centered over the north Atlantic (31.5°N, 47°W). About 1200 GMT the cold front overtook the stationary front to the south and became stationary itself. It now extended southwestward through central Maryland and Virginia approximately 280 km north of the experiment area. Thus, a southwestward flow continued over the project regions until the cold front shifted southward past the region of interest sometime between 0000 GMT and 0600 GMT the next day. The result of these atmospheric motions lead to generally steady winds with a long fetch oriented towards the NE. Therefore, by the afternoon of June 2, the seas were undoubtedly full-developed as definded by Pierson and Moskowitz (1964). Ship reports gave the dominant wave heading to be consistently 40 degrees.

June 4: (Figures IV-5a to 5d)

After the above-mentioned front had passed, the area remained under the influence of a high pressure ridge

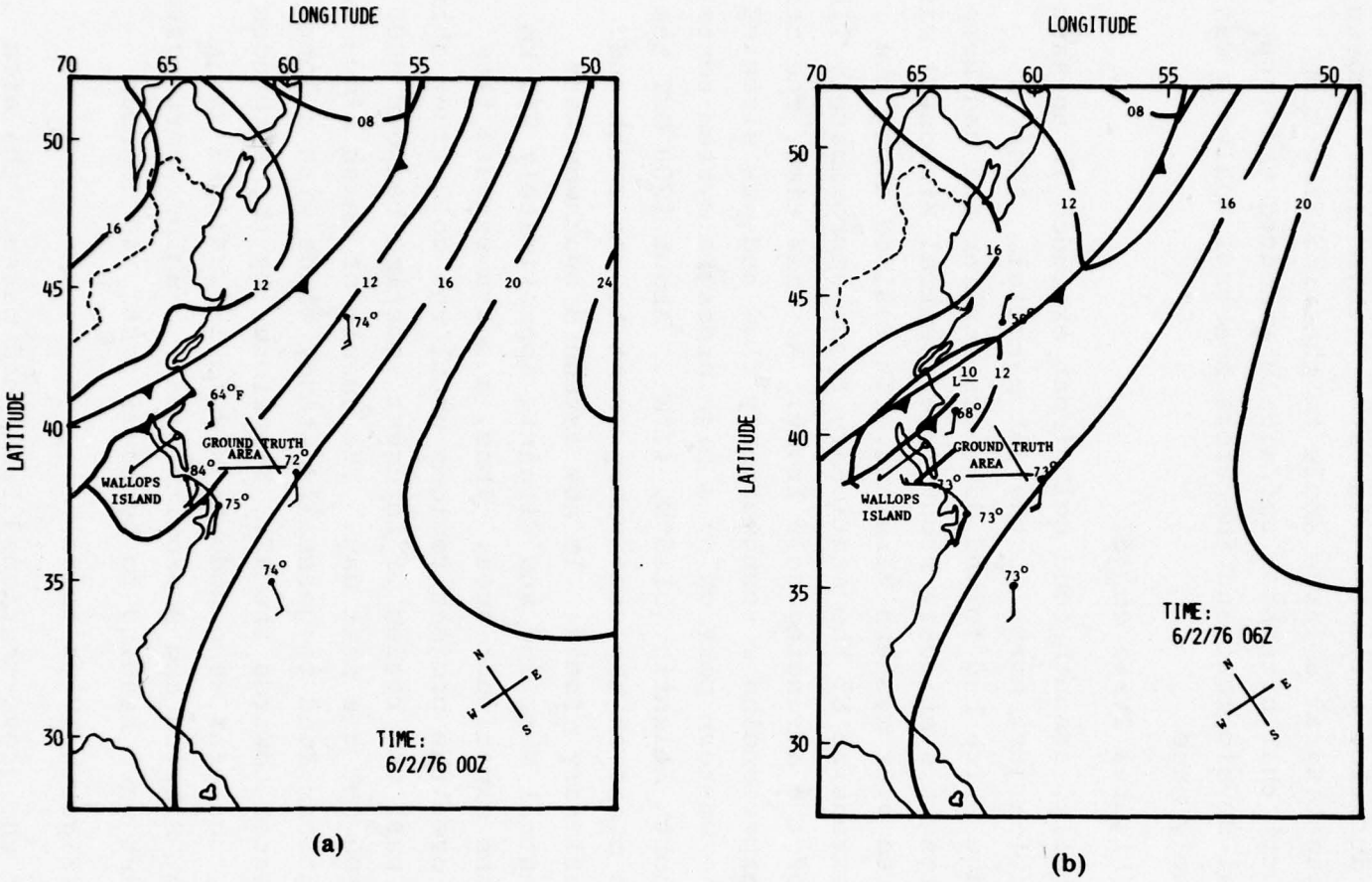
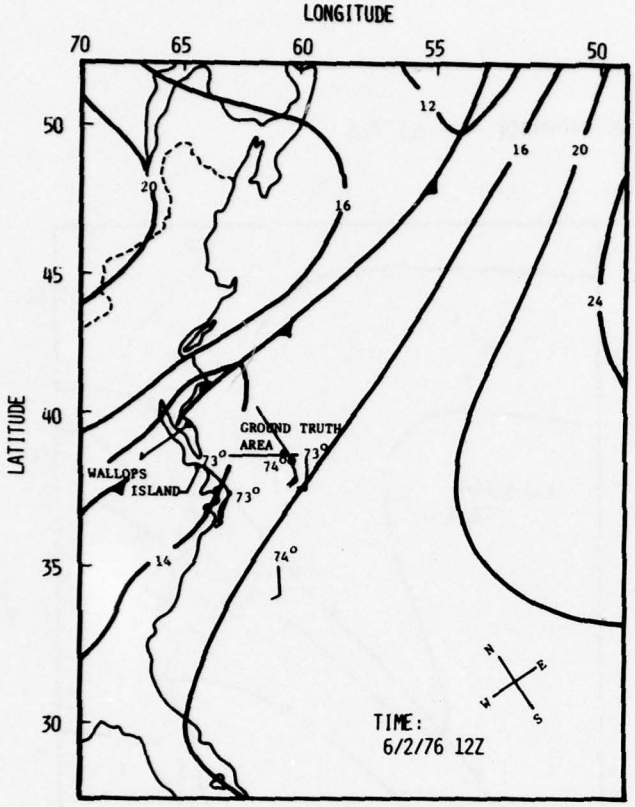


Fig. IV—4 — Meteorological data on 6/2/76 (Continues)



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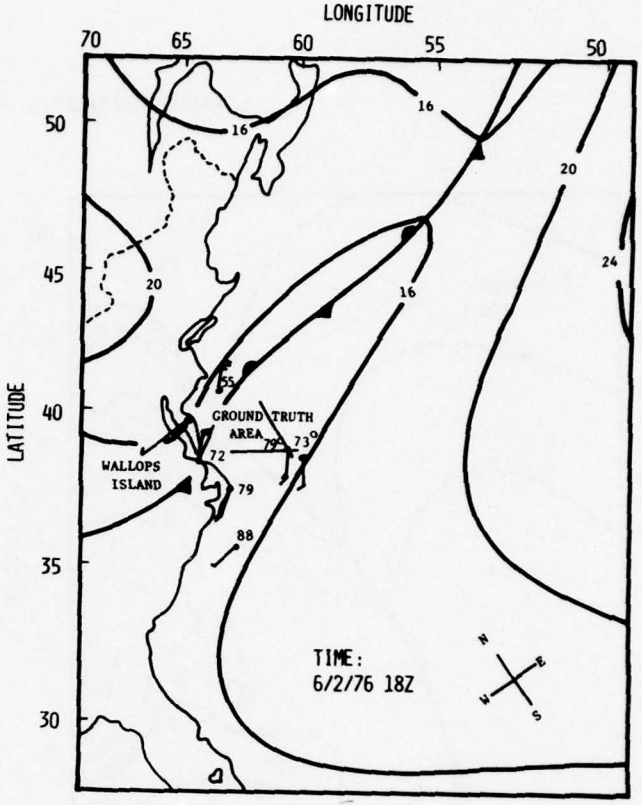

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Fig. IV—4 — Meteorological data on 6/2/76 (Continued)

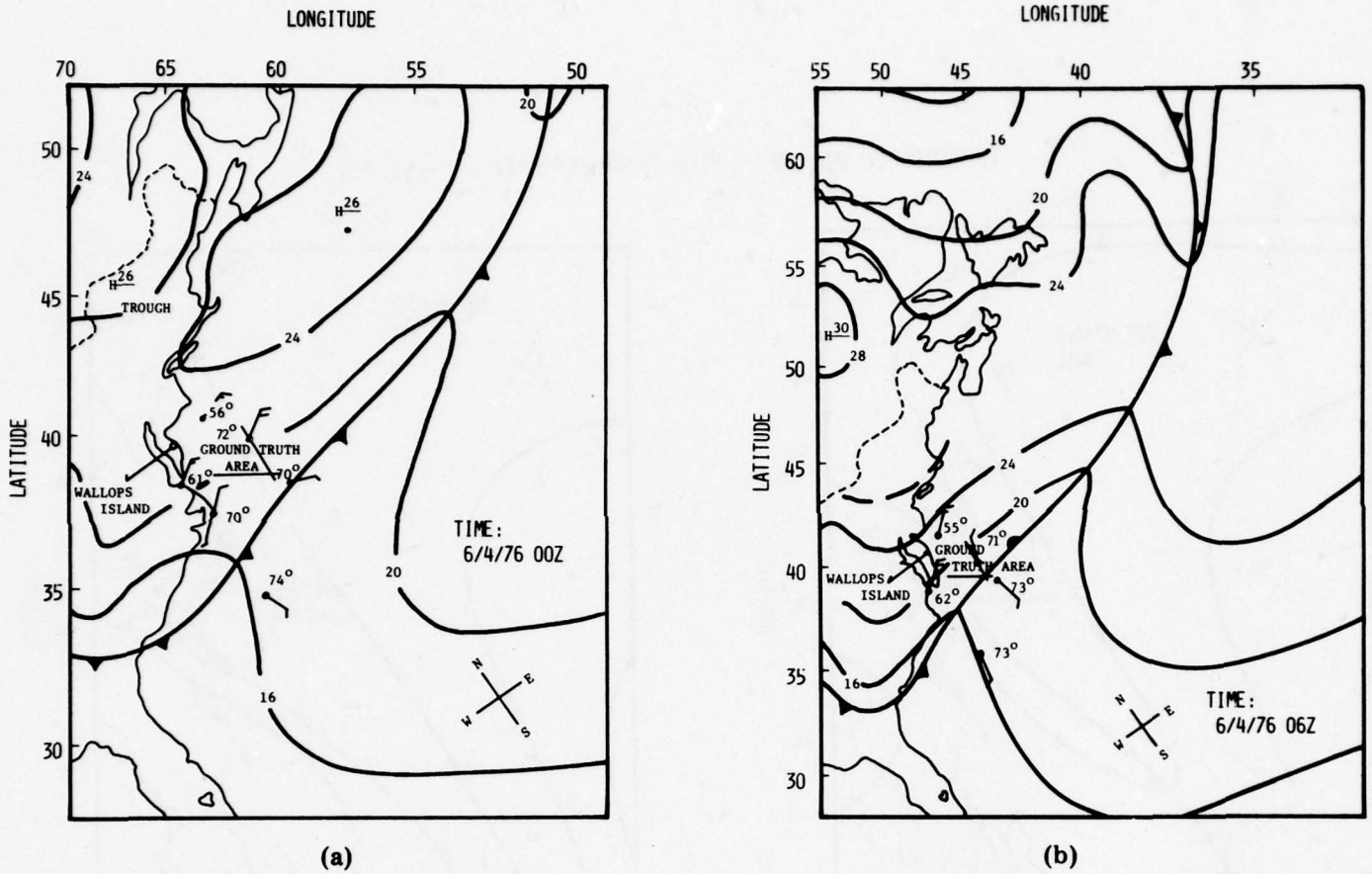
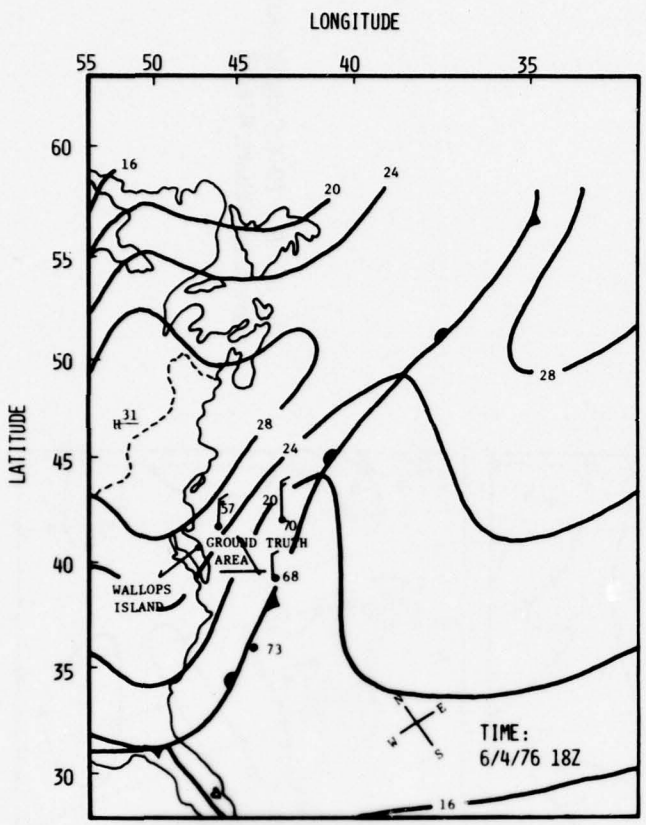


Fig. IV—5 — Meteorological data on 6/4/76 (Continues)



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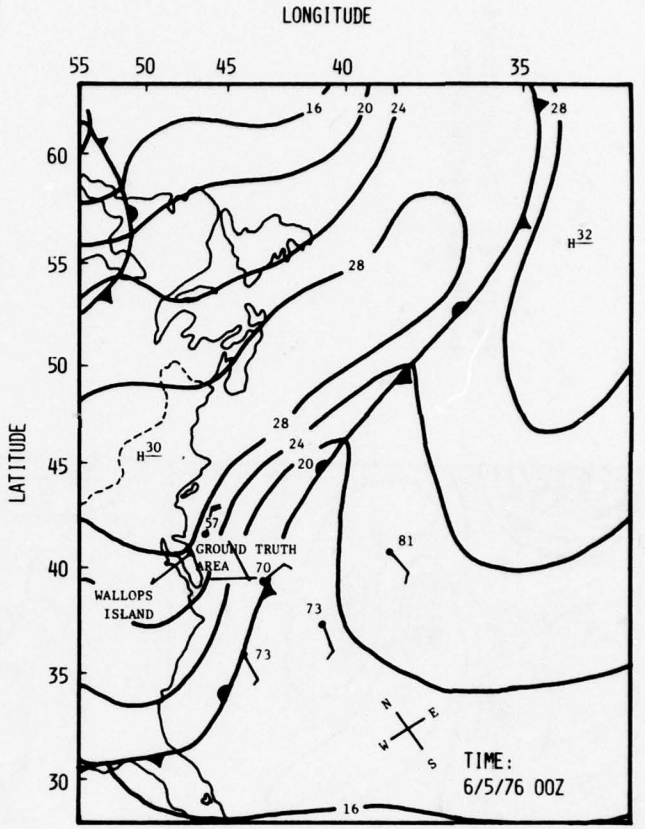

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Fig. IV—5 — Meteorological data on 6/4/76 (Continued)

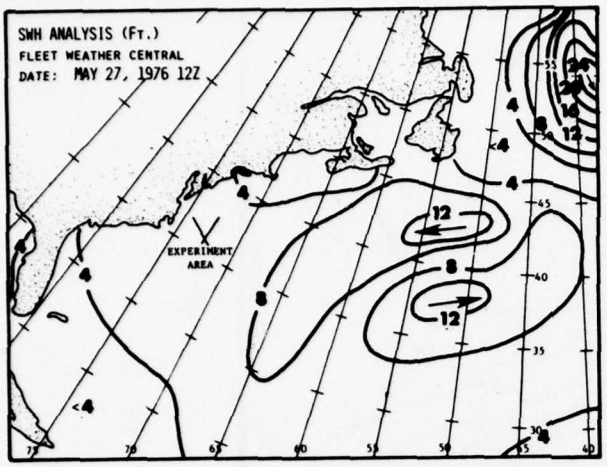


Fig. IV—6 — FNWC significant wave height chart, 5/27/76

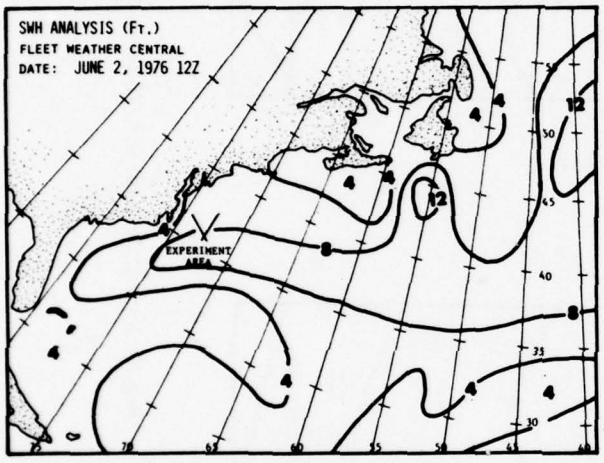


Fig. IV—7 — FNWC significant wave height chart, 6/2/76

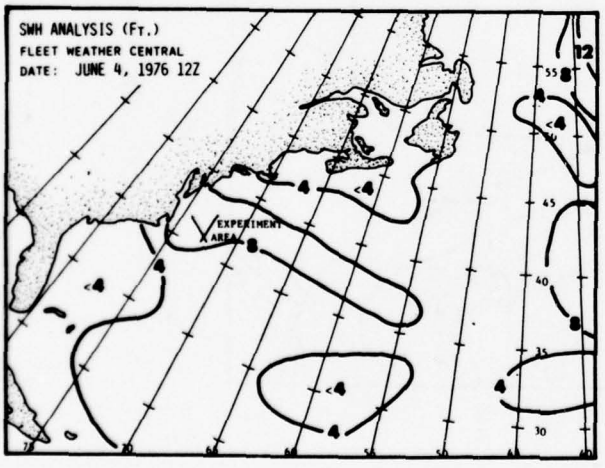


Fig. IV—8 — FNWC significant wave height chart, 6/4/76

extending in a E-W direction over the Great Lakes. The associated southwesterly flow continued through June 4. The highest SWH during the project occurred on this day, however, the low wind speeds indicate that this sea state is due mostly to swell generated earlier that morning. Rain and clouds did hamper the laser's operation but not seriously and the wind-wave radar's waveguide was flooded prohibiting its operation. The ship reported the dominant wave direction to be constant at all stations with a heading of 225°. No weather chart for 1200 GMT was available.

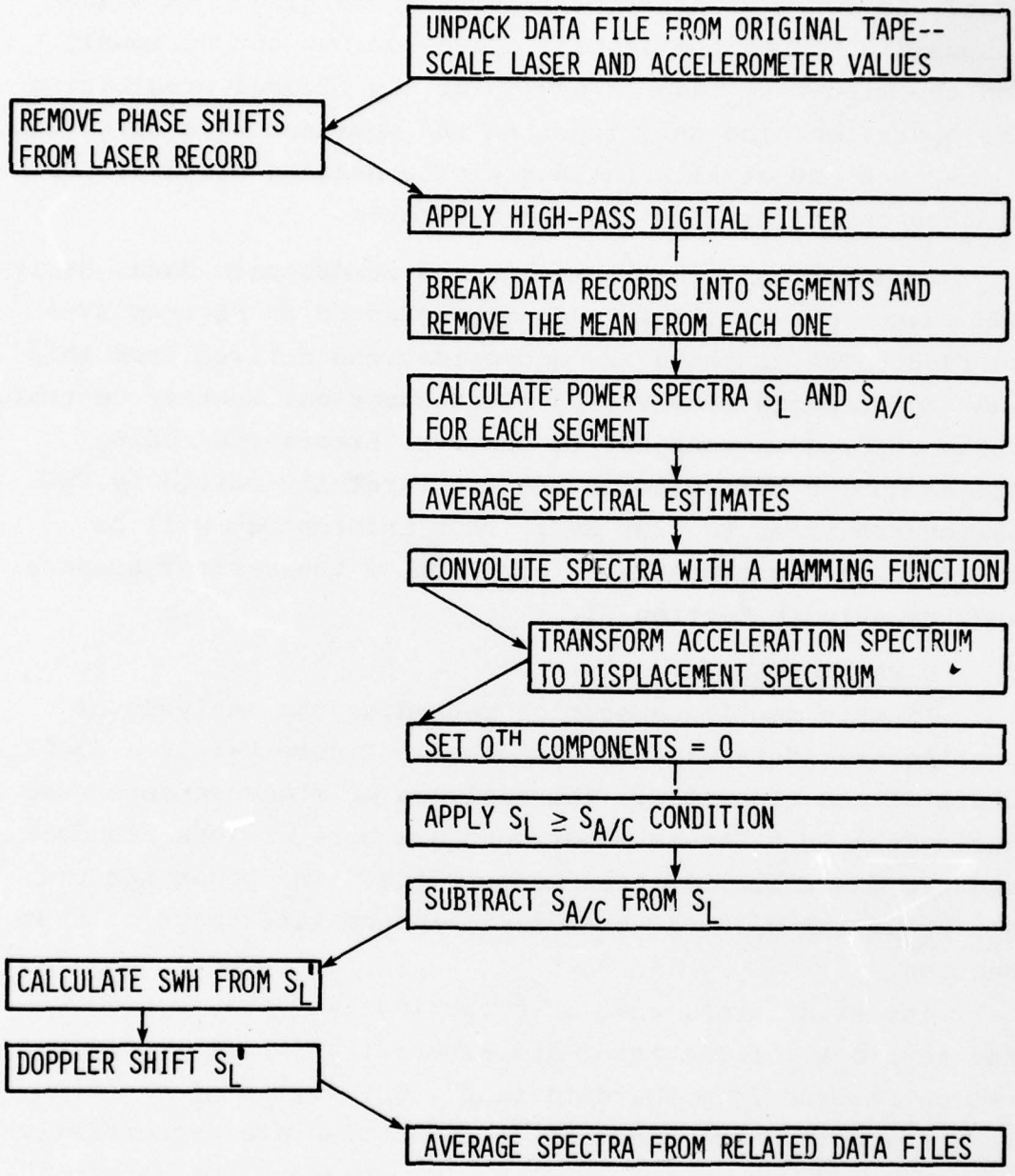
In addition to hydrographic and atmospheric data, daily SWH charts are available and are presented in Figures IV-6 to IV-8. The contours are approximations derived from ship and buoy reports received by Fleet Numerical Weather Central. These reports are subject to observer errors and coding errors during transmission and are carefully edited by FWC. All charts refer to 1200 GMT. This information will be included in the comparisons of SWH from the various sensors and the ship in Section VI.

V. DATA PROCESSING

In this section specifics regarding the analysis of profilometer data will be discussed. Figure V-1 is a flow chart of the algorithm. The analyses of other sensors used during the Gulf Stream Experiment are more or less standard and are described in other manuscripts. The power spectra S_L, $S_{A/C}$, and S_L' will be defined in the later part of this section.

The first step, that of unpacking the data, concerns the retrieval of the laser and aircraft vertical acceleration records from the data tape. The format of the tape is not simple since a number of quantities are sequentially recorded and a masking technique is necessary for picking out particular data sets. The manner in which the data was recorded is as follows. The basic data block is called a file. At the beginning of each file is a header which

DATA ANALYSIS FLOW CHART - AIRSPEC 5*



(* SEE APPENDIX F)

Fig. V—1

contains the file number, date, time, altitude, and radar sampling scope settings. Each file contains 32 records which in turn contains one INS latitude and longitude fix. A record also contains 256 sweeps. A sweep is composed of one sample from each of seven analog input channels and 160 samples from the radar sampling scope which define the recorded radar return waveform. The sweep rate is approximately 90 Hz which implies a sample interval of 1/90 seconds. The analog channels (see Figure III-]) are INS aircraft pitch, INS aircraft roll, INS aircraft vertical acceleration, laser profilometer, time of day, PRT-5 and a spare. The eighth input is the radar. The pulse rate of the radar is 90 KHz, but the system is designed with an integrating circuit which averages about 6 return pulses before the signal is feed into the analog-to-digital converter which is triggered at 15 KHz. The magic number of 167 samples per sweep is derived by the division, 15 KHz/90Hz. Therefore, the recorded radar pulse is comprised of a sample from each of 160 consecutive waveforms from the A/D converter. Each file contains 8192 = 2^{13} sweeps and an seven-track tape can hold seven files. After unpacking, the values of each quantity are transformed from millivolts to physical units using the appropriate calibration constants.

After the laser phase shifts have been removed, both the accelerometer and the laser records are high-pass filtered. The purpose is two fold. First, any spectral analysis should include a "prewhitening" of the data to remove segments of components whose periods are longer than the data segment and also to decrease the sidelobes of the transform that are introduced by analyzing data intervals of finite length. The second reason is to remove aircraft motion contamination which will be discussed later.

The numerical filter applied was the so-called "Martin Filter" (Martin, 1957). It is a symmetric, non-recursive

filter which features a sine termination to the gain function and a correction which insures unity gain at $\tau = f_c/f_s = 0$ (f_c = cut-off frequency, f_s = sample frequency). The sine termination is introduced to avoid large oscillations in the gain function due to a sharp cut-off (Gibbs phenomenon). Since the filter is a low-pass filter, the high-pass filter weights, W_H, are derived from the low-pass weights, W_L.

$$W_H(n) = \begin{cases} 1 - W_L\ (0) \\ \\ W_H\ (-n) = -W_L(n) \qquad\qquad n = (1,N) \end{cases} \tag{4}$$

There are 2N+1 weights in the filter. As with any filter, once N exceeds some value, it becomes more efficient to apply the filter in the frequency domain rather than the time domain. The other two parameters required to generate the weights are f_c and the "slope of weights", h, which originates in the sine termination scheme.

The domain of τ is (0, 0.5). With the value of f_s and the size of the data block used, the value of τ is very small and this can cause problems with the filter gain function. Several factors determine how the filter is to be designed. To begin, the flight patterns for the laser included five legs and during each leg three files of data were taken. In order to have an acceptable confidence interval, a compromise had to be reached between the length and the number of data segments to be analyzed and averaged. Since the filter removes 2N points from each file and because the FFT requires 2^p points, the selection was 22.8 second data blocks = 1/4 file or 2^{11} points per analysis. Therefore, three analyses per file could be made, and nine spectral estimates per leg could be averaged. The 22.8 second interval was chosen because it was felt that a

representative sample of the surface would be obtained over a distance equal to 22.8 S x 55 m/s $\approx$ 1250 m. The 55 m/s figure is the lowest ground speed of the aircraft. Thus. a prewhitening filter would require $f_c \approx 1/20\ s^{-1}$, (Davis, 1974). Since f_s = 90 Hz, $\tau = 5.6 \times 10^{-4}$. No filter with $N \leq 1024$ points could be obtained for such a τ that had an actual cut-off anywhere near 20 seconds. The alternatives are to increase f_c, decrease f_s, or both.

At this point, aircraft motion plays a part in filter design. Originally, the accelerometer was to be used as the primary method for aircraft motion removal. However, most aircraft energy has periodicities above 10 seconds and would be concentrated in the lower harmonics of our transform. These are the least accurately estimated. The error in these harmonics is increased when the power spectrum of the acceleration record is transformed to one of aircraft displacement. This transformation is accomplished by dividing each component by ω^4, ω is the circular frequency. Therefore, a higher cut-off frequency than 0.05 s^{-1} was advisable. It should also be remembered that the accelerometer was not of the highest quality in the first place.

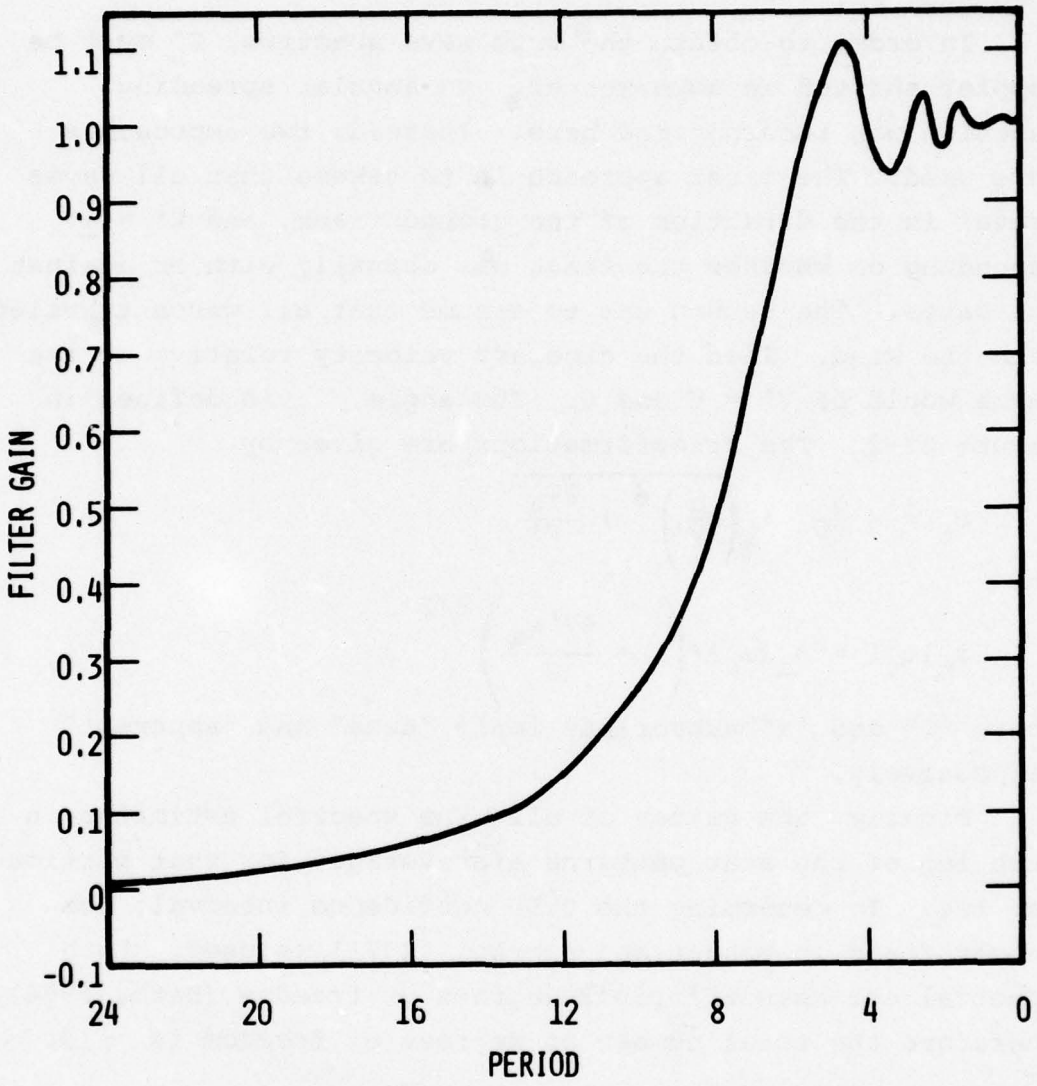
Why not reduce f_s by digitizing at a lower rate? Many laser-profilometer derived ocean wave spectra available in the literature curiously deviate from what is expected theoretically and from other empirical methods (Parsons and Goodman, 1975). Therefore, we opted for the highest sampling resolution available which was f_s = 90 Hz rather than going to a larger spacing. At 100 m/s aircraft speed, a sample every meter would be obtained.

With these considerations, a trial and error approach was made to find the best filter. The compromise was between the 10% attenuation point, the shape of the filter ramp, and the size of the sidelobes. Figure V-2 shows the

filter gain function. The 10% attenuation point is at approximately 6 s. The filter parameters are $\tau = 0.0012346$, $h = 0.0001$, and $N = 512$. This filter requires a great deal of time to convolute with a data file. Actually, the reduction of f_s by a third or a fourth would sharpen up the filter response greatly, and would make the filter more sensitive to the value of f_c selected.

After the Fast Fourier Transform (FFT) and application of the Hamming convolution to each spectrum, the above mentioned transformation is carried out on the acceleration spectrum to produce the aircraft displacement spectra, $S_{A/C}$. Through the same FFT and Hamming function the power spectra, S_L, derived from the laser profilometer measurements are also evaluated. It should be noted that strong objections may be raised about applying a spectral window in the frequency domain instead of the time domain (see Davis, 1974). In this instance, the filter applied to the data was probably adequate for reducing the sidelobes. The problem is further alleviated by the fact that the wave spectra are not characterized by sharp peaks but are rather smooth with gradual slopes. Since the means were removed from each data segment prior to the FFT, no energy should reside in the zeroth harmonic. However, because of the problems with the filter ramp and the relatively large spacing between adjacent harmonics in this portion of the spectrum, the zeroth harmonic usually did have a finite value after the Hamming function convolution. It was arbitrarily set to zero.

Another condition was implemented as well. No component of $S_{A/C}$ should exceed S_L. Ideally S_L should always be equal to or greater than $S_{A/C}$ because it is the sum of two uncorelated motions. If $S_{A/C}$ did exceed S_L, they were considered equal and due to the aircraft and S_L was set equal to zero. All other components of $S_{A/C}$ were subtracted from those of S_L and residual spectrum is defined as S_L'. The significant



RESPONSE FUNCTION OF HIGH-PASS DIGITAL FILTER

Fig. V—2

wave height, SWH, was calculated from the result given in Neumann and Pierson (1966).

$$H_{1/3} = 4\sqrt{\sigma^2} \tag{5}$$

where σ^2 is the total variance or power in the residual spectrum, S'_L.

In order to obtain the true wave spectrum, S'_L must be doppler shifted in some manner. No angular spreading function was incorporated here. Instead, two approaches were used. The first approach is to assume that all waves travel in the direction of the ground track, and $V' = \pm V$ depending on whether the track was actually with or against the waves. The second was to assume that all waves traveled with the wind. Then the aircraft velocity relative to the waves would be $V' = V \cos \theta$. The angle, θ, is defined in Figure II-2. The transformations are given by

$$\omega_t = -\frac{g}{2V'} + \sqrt{\left(\frac{g}{2V'}\right)^2 + \frac{g\omega_a}{V'}} \tag{6}$$

and

$$\phi_t(\omega_t) = \phi_a(\omega_a) \cdot \left(1 + \frac{4V'\omega_a}{g}\right)^{1/2} , \tag{7}$$

where "t" and "a" subscripts imply "true" and "apparent" respectively.

Finally, the values of all nine spectral estimates in each leg of the star patterns are averaged for that particular leg. To determine the 0.90 confidence interval, the result found in Bendat and Piersol (1971) is used. Each spectral estimate affords 2 degrees of freedom (Bath, 1974). Therefore the total number of degrees of freedom is ≈ 18.

$$\frac{n}{\chi^2_{n,\frac{\alpha}{2}}} \leq \frac{G(f)}{\hat{G}(f)} < \frac{n}{\chi^2_{n,(1-\frac{\alpha}{2})}} , \tag{8}$$

where n = number of degrees of freedom, α is a parameter

determining the confidence interval desired, $(1-\alpha)$, $G(f)$ is the estimated spectrum, $\hat{G}(f)$ is the true spectrum, and χ^2 is the chi-square function. Equation (8) yields (0.62, 1.9) for the 90% interval.

VI. PRESENTATION AND DISCUSSION OF RESULTS

A. Wind and $H_{1/3}$

Table 3 contains all of the results for wind and significant wave height. As for the wind-wave radar, due to the malfunction of a transmitting cable on 5/27/76 and clogged horn by rain on 6/4/76 only the data taken on 6/2/76 was consistently good during the 305 m patterns. For this reason, only one data point was obtained. It should be noted that the algorithms for the wind-wave radar relates the wind speed to a 12.5 m reference level, while the ship's anemometer is positioned 24.5 m above mean sea level. The elevation corresponding to the NWS values is not known to us. The aircraft speeds are given for the 3048 m transects in order that the distance between measurements can be calculated. The actual positions and orientations of the patterns and legs are shown in Figures VI-1 to VI-4b. All of the 3050 m tracks proceed in a southerly direction and therefore SWH values near the end of the track relate more closely to Pattern 2. Initial values from the high flight radar (3050 m) were obtained in locations closer to Pattern 5 although a time lag of 3 to 4 hours may exist between those measurements. The laser results do show some spatial inhomogeneities between legs, ie. Pattern 2 on 5/27/76. The laser data is most consistent on 6/2/76. Unfortunately, there were no satellite overflights coincident to these measurements.

B. Ocean Wave Spectra

The data selected for spectral analysis was the data obtained on 6/4/76. Figures VI-5a to VI-14b are spectra from the two star patterns flown that day. Each figure contains two plots, the ocean wave spectrum and the aircraft

Table 3 — Wind and SWH Results

	DATE PATTERN-LEG	NRL RADAR	LASER PROFILOMETER	SHIP REPORT	NWS/FWC	COMMENTS
WIND (m/s) Time=15:16	6/2/76	8		8.7	5-10	
$H_{1/3}$ (m)	5/27/76					
13:21	3048m	2.45			1.2-2.4	A/C Speed=
13:25	3048m	2.60				88.3 m/s
13:27	3048m	2.00				@ 3048 m
13:31	3048m	1.94				
15:06	2-1		1.23	1.4		
	2-2		1.35			
15:24	2-3		1.80			
	2-4		1.26			
15:42	2-5		2.06			
	6/2/76					
13:18	3048m	1.65			1.2-2.4	A/C Speed=
13:23	3048	1.70				85.5 m/s
13:25	3048m	1.92				@ 3048 m
14:56	2-1		1.88	1.8		
	2-2		1.72			
15:16	2-3		2.12			
	2-4		1.78			
15:39	2-5		1.83			
	3-UW		1.90			
	5-1		1.98			
16:46	5-2		1.96			
	5-3		1.99			
17:05	5-4		1.90			
	5-5		1.89			
	6/4/76					
13:18	3048m	3.27			2.4-3.0	A/C Speed=
	3048m	3.26				87.5 m/s
	3048m	3.25				@ 3048 m
	3048m	3.29				
15:02	2/1		2.77	1.2		
	2/2		2.94			
15:28	2/3		2.84			
	2/5		2.64			
15:51	2/4		2.36			
	3-UW		2.83			
	3-DW		3.27			
16:48	4-UW		3.33			
	4-DW		3.72			
	5-1		3.34			
17:14	5-5		3.32			
	5-2		2.67			
17:32	5-3		2.72			
	5-4		3.60			

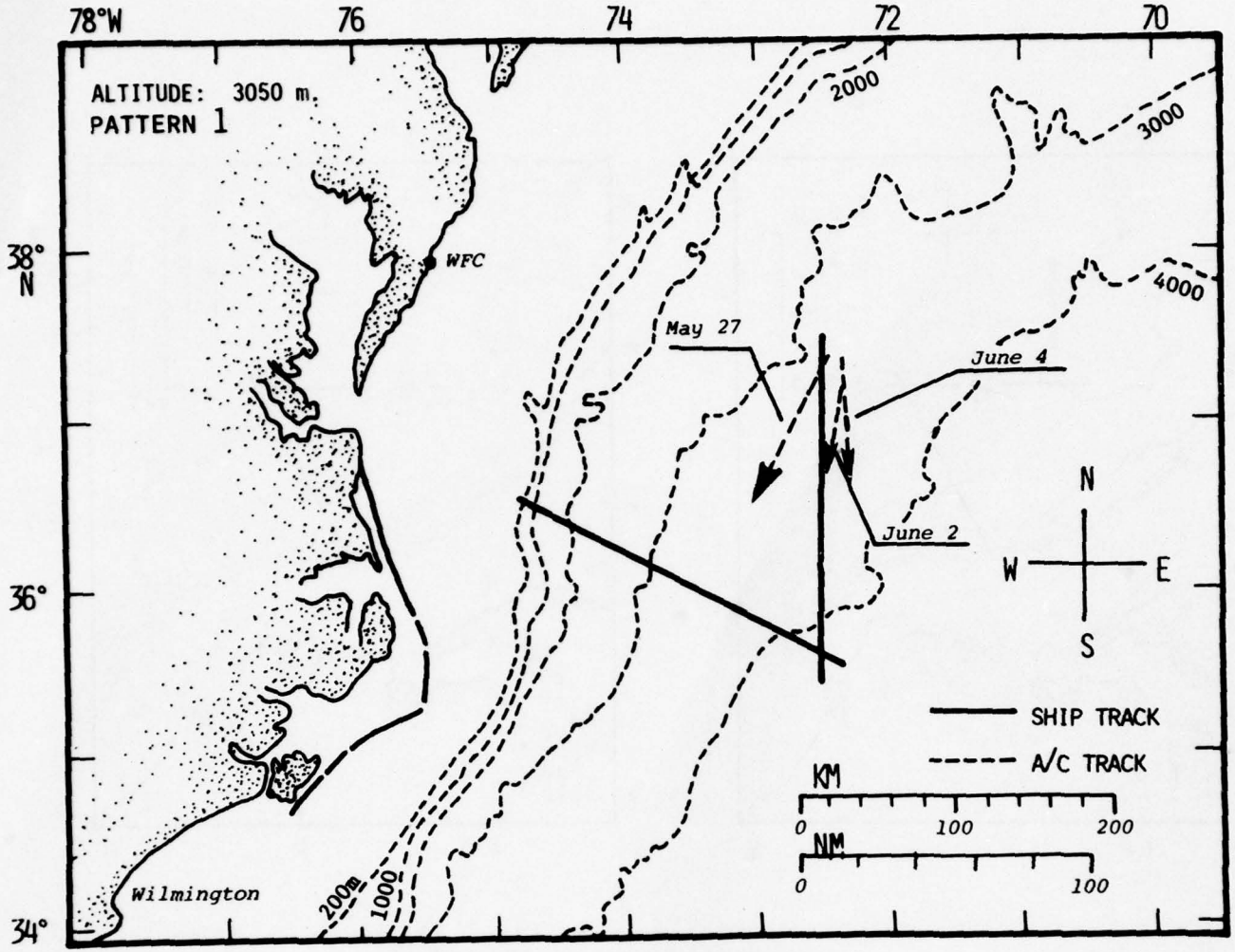
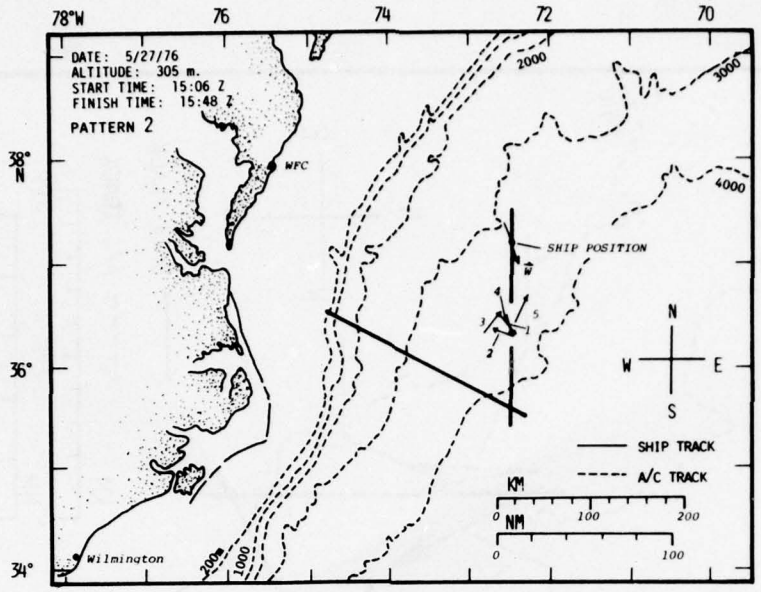
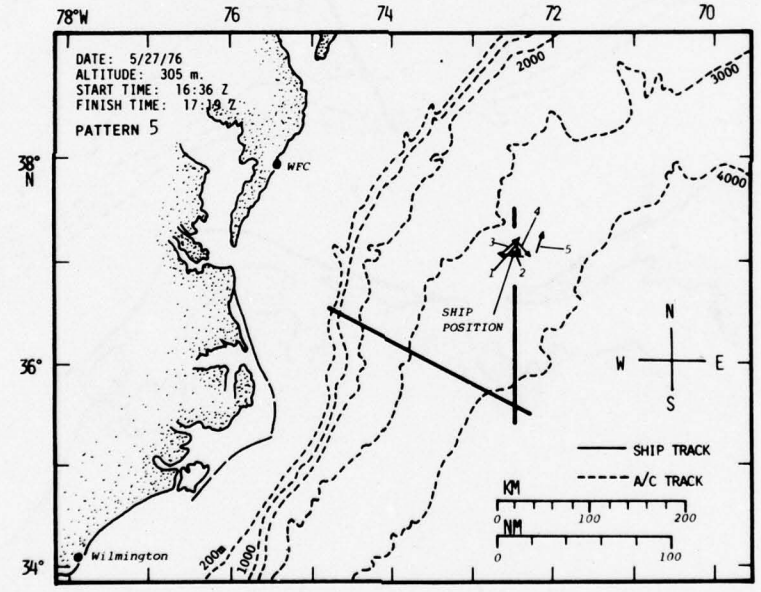


Fig. VI—1 — Flight tracks at 3050 meters

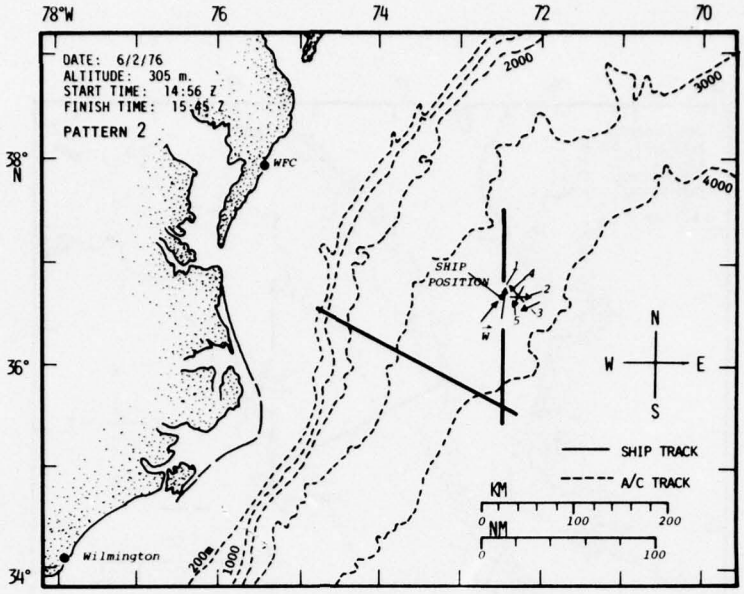


(a)

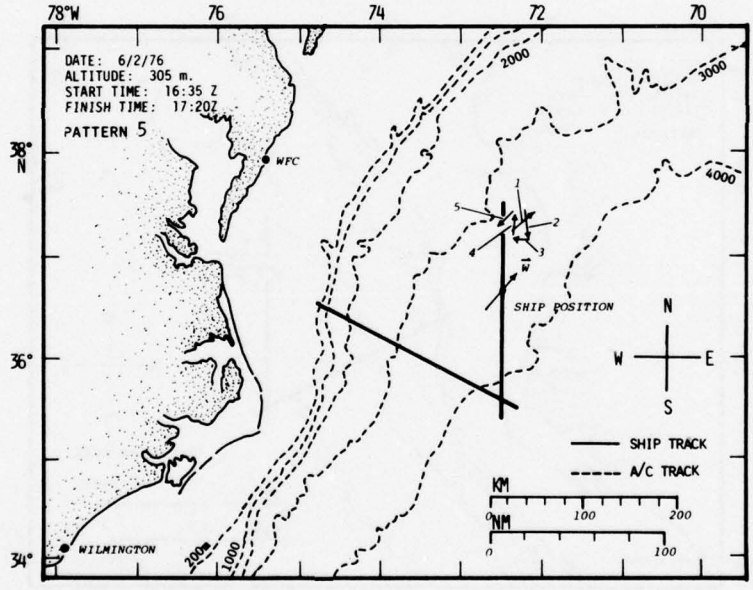


(b)

Fig. VI—2 — Star patterns on 5/27/76

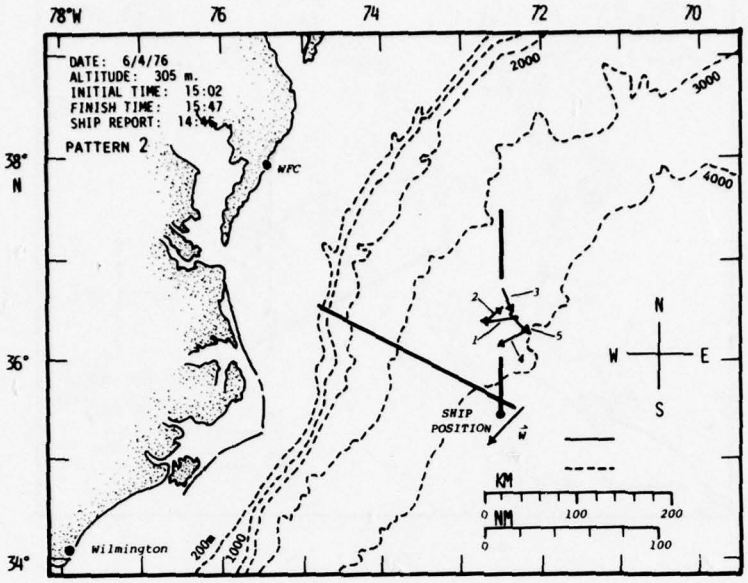


(a)

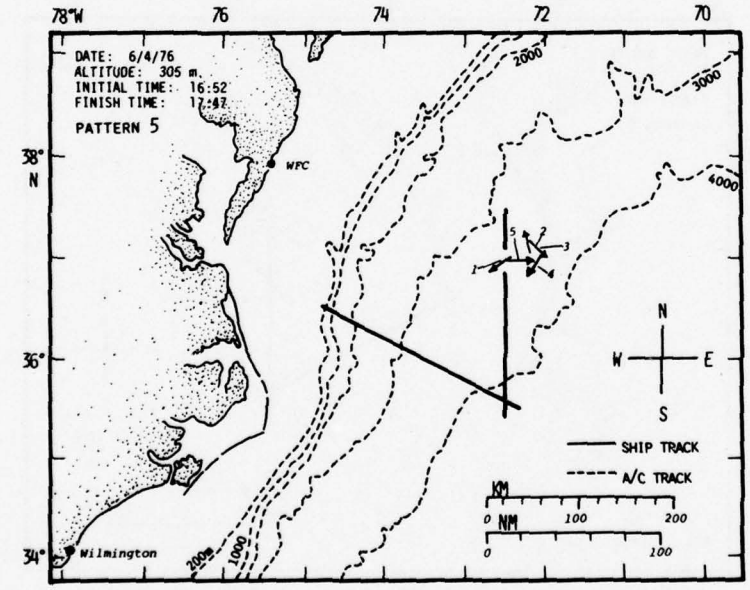


(b)

Fig. VI—3 — Star patterns on 6/2/76



(a)



(b)

Fig. VI—4 — Star patterns on 6/4/76

displacement spectrum. The convention for "TAPE" printed on each plot is data tape number--pattern number (Figure II-1)--leg number. The plots are arranged in the order of increasing aircraft track deviation from the wave direction. The plots are log-log covering five orders of magnitude on the ordinate and three on the abscissa. The plots of the aircraft motion power spectral density demonstrates what was discussed in Section V regarding the problems of estimating that parameter using short data lengths ($\approx$22.5 s). Since the energy resides in a frequency interval where spectral resolution is relatively coarse and where the transformation from acceleration to displacement is particularly sensitive, the proper elimination of the side lobes introduced by the discrete finite Fourier transform is difficult. For this reason, those curves do not break downward on the low frequency end. This problem might have been avoided had the spectral window been applied in the time domain before the mean was removed. Also, components with amplitudes too low are not plotted. When comparing the standard deviation of the aircraft motion to the significant wave height (both values supplied on each plot), large differences in the first is often seen between data segments even though $H_{1/3}$ estimates usually show little variation. This fact indicates that the algorithm handles this rather perplexing situation reasonably well. Its performance would certainly improve if the data set could allow for longer data segments and a sharper filter gain cutoff as argued in Section V. Figure VI-15 is provided in order to demonstrate the effect of erroneous estimation of aircraft motion on the SWH. Appendix D gives the derivation and definitions for this plot.

For each leg, two spectra are shown. The "a" designation corresponds to a doppler shift which assumes that the waves are traveling in a direction parallel to the

flight track, i.e. $\theta = 0°, 180°$. The "b" relates to the assumption that the waves propagate parallel to the wind direction. The direction of the dominant wave component as given by the ship report was perfectly downwind on that day. However, if the Pierson-Moskowitz model is used to relate SWH to wind speed,

$$H_{1/3} = 0.0212\ U^2_{19.5} \quad , \tag{9}$$

the wind speed during the time of flight is insufficient to generate the seas that were encountered. Indeed, the winds had gradually subsided from higher values (ship report: 10-12 m/s winds, 4-6 m seas) early that morning. Therefore, the seas were not in a purely generation phase. Nonetheless, the spectra from upwind and downwind tracks do conform to a 5:1 slope as expected.

Included are two additional spectra (Figures VI-16, 17) taken from upwind and downwind flights near Newfoundland during February-March, 1976. The seas were much higher and offered a good test of the algorithm's performance because of high wind speeds experienced by the aircraft (up to 40 knots). As can be seen, the 5:1 slope is maintained. Also, when these are compared with the Gulf Stream spectra (lower sea state) from similar tracks, the plots align perfectly showing that the high frequency components do saturate and are maintained as $H_{1/3}$ increases. Spectral growth does proceed in the manner predicted by Phillips and aptly depicted in Kitaigorodskii (1973). It should be noted that line-profiled data taken from a directionally dispersive system will produce power spectra that are distorted to some degree. The more directional the wave field is, the smaller the distortion (see Appendix E). The spectra shown here tend to exhibit the least distortion

Fig. VI—5a

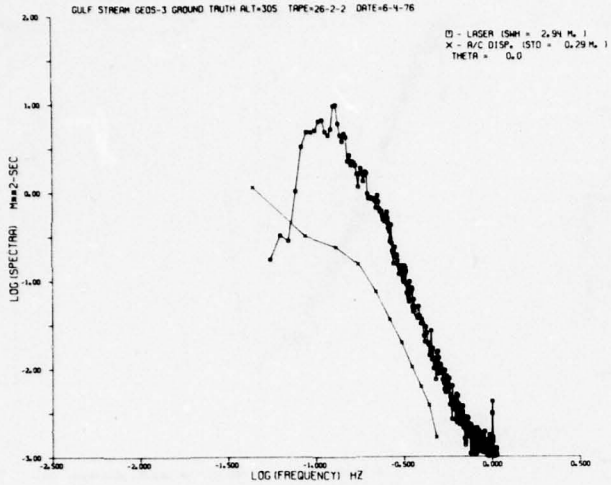
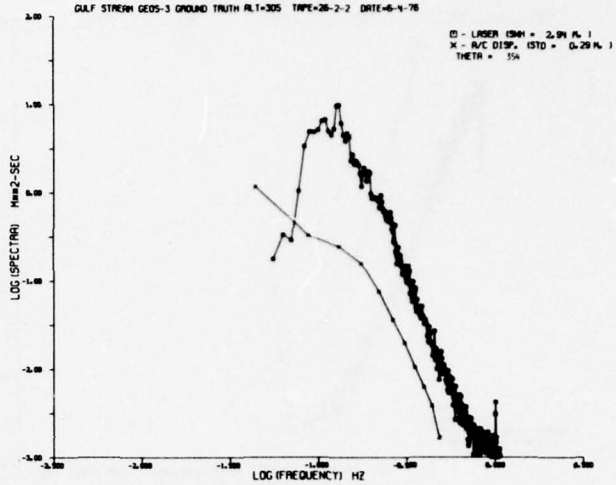


Fig. VI—5b



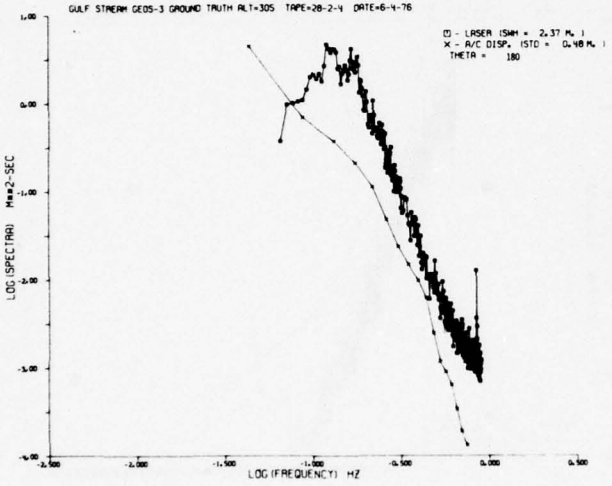


Fig. VI—6a

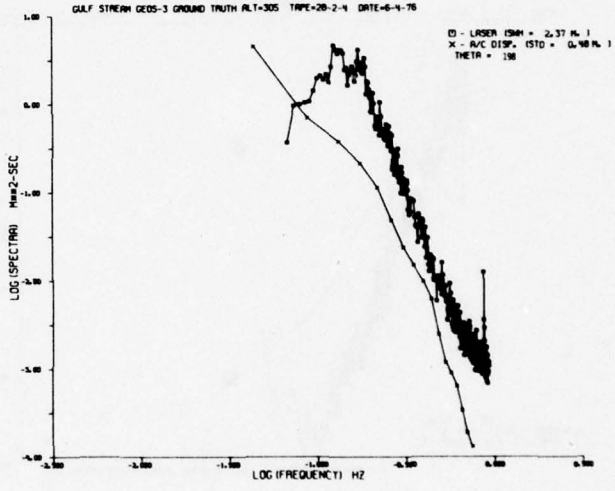


Fig. VI—6b

Fig. VI—7a

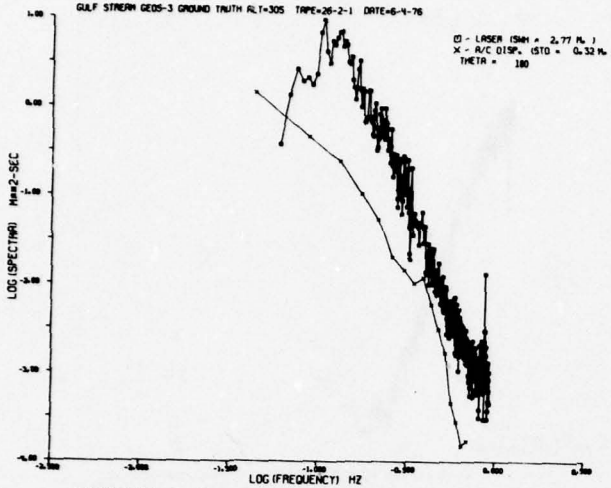
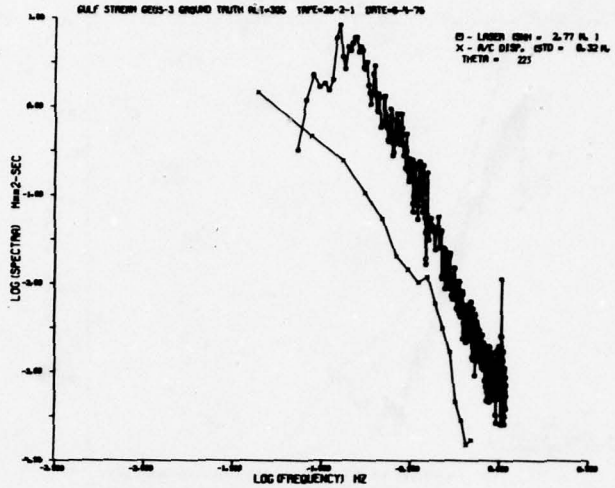


Fig. VI—7b



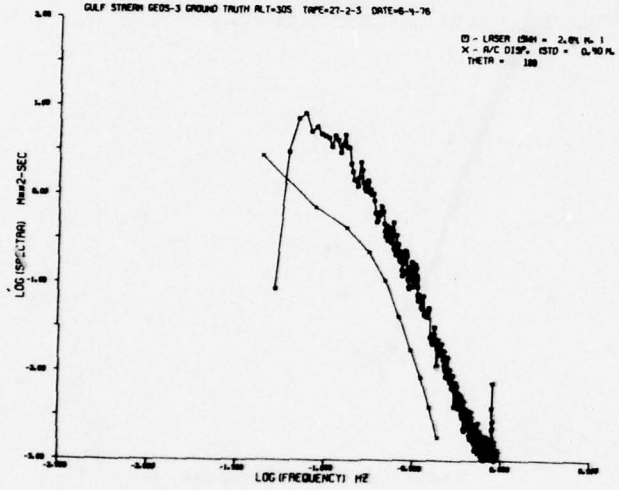


Fig. VI—8a

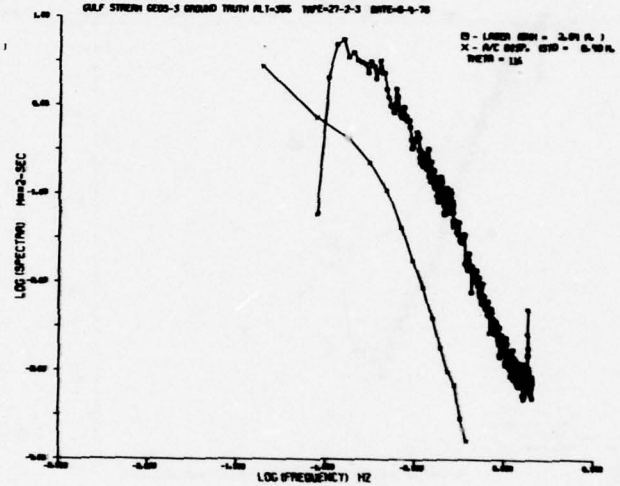


Fig. VI—8b

Fig. VI—9a

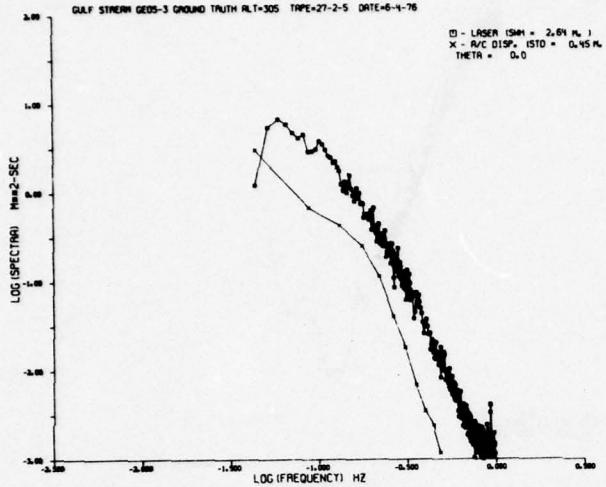


Fig. VI—9b

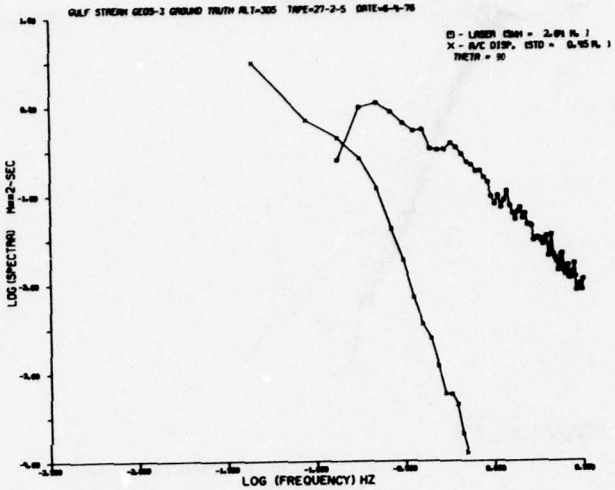


Fig. VI—10a

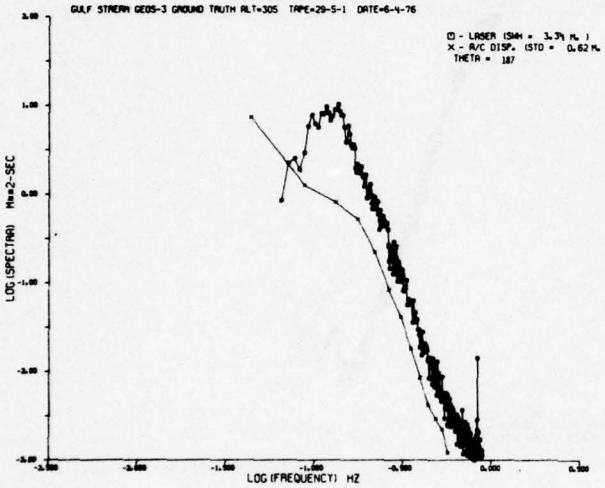


Fig. VI—10b

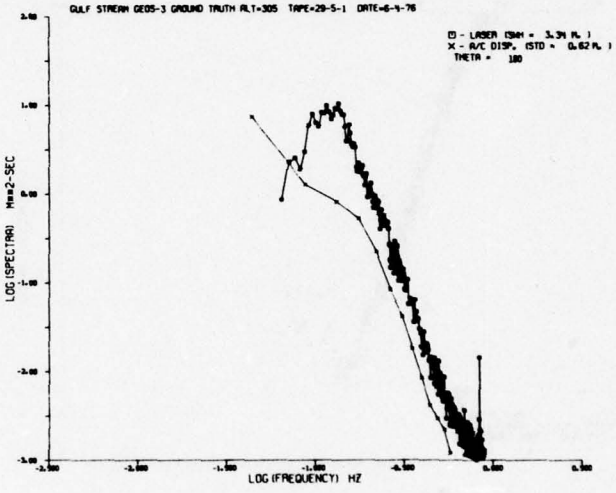


Fig. VI—11a

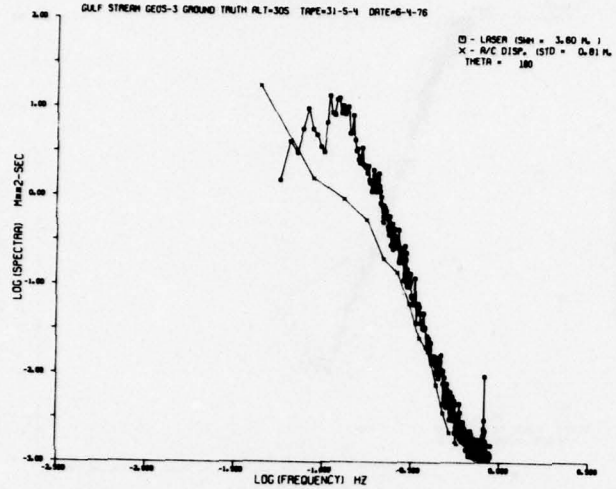
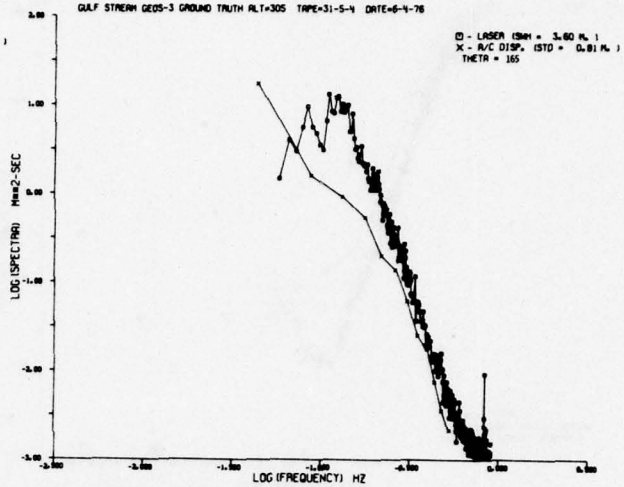


Fig. VI—11b



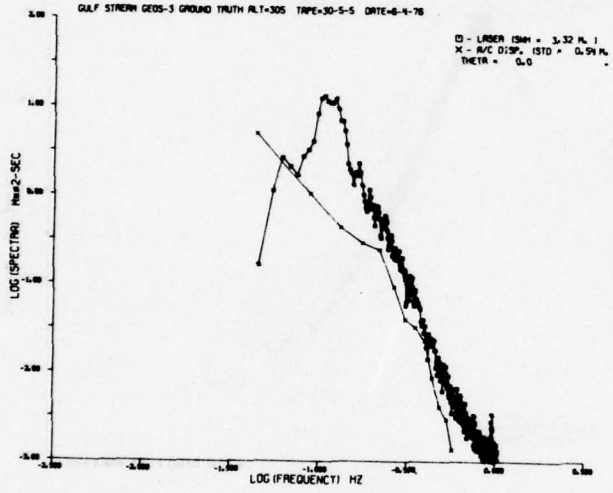


Fig. VI—12a

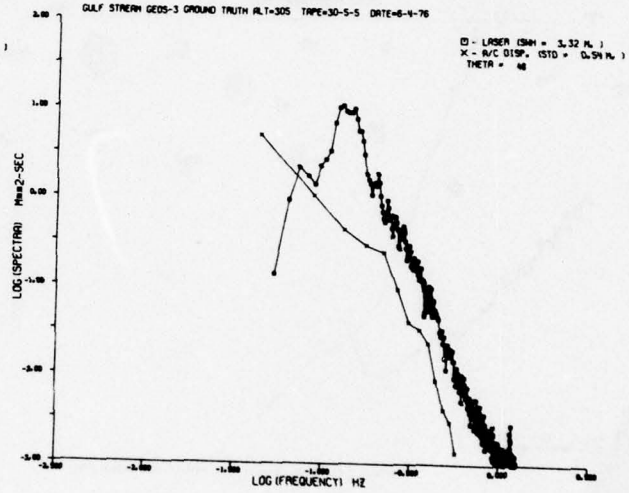


Fig. VI—12b

Fig. VI—13a

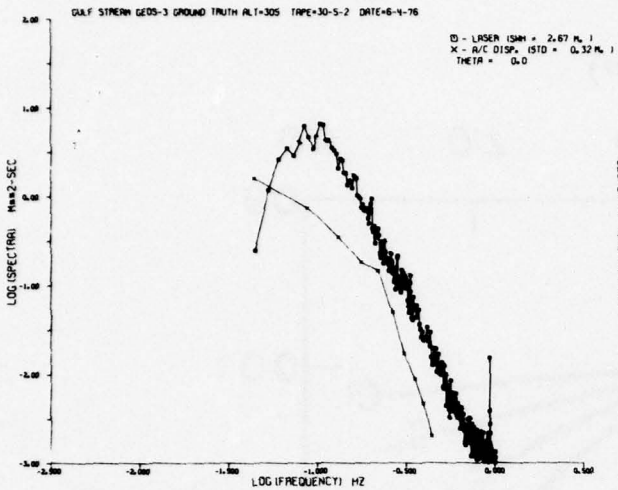
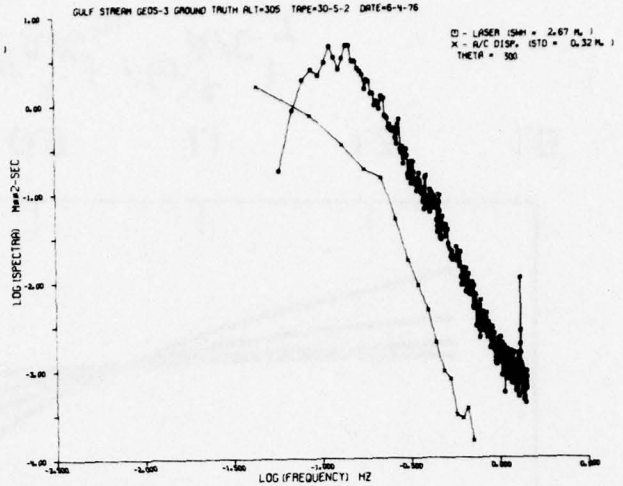


Fig. VI—13b



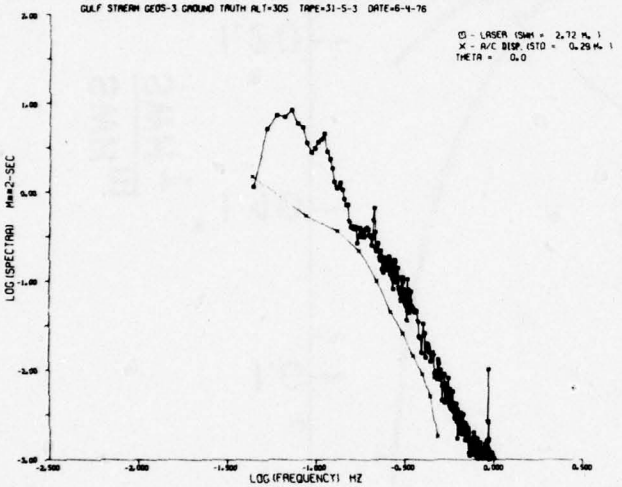


Fig. VI—14a

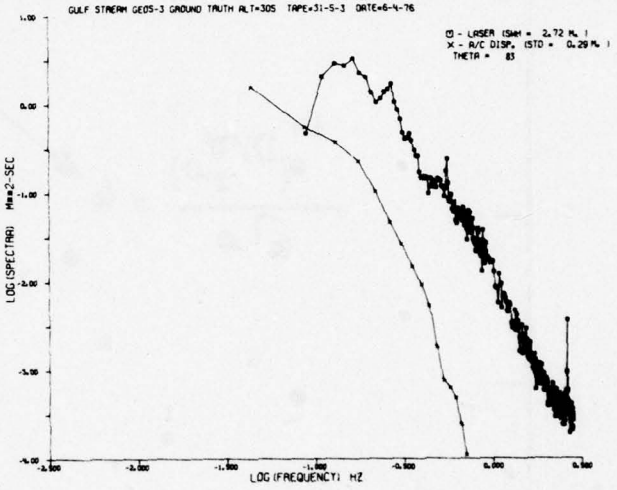


Fig. VI—14b

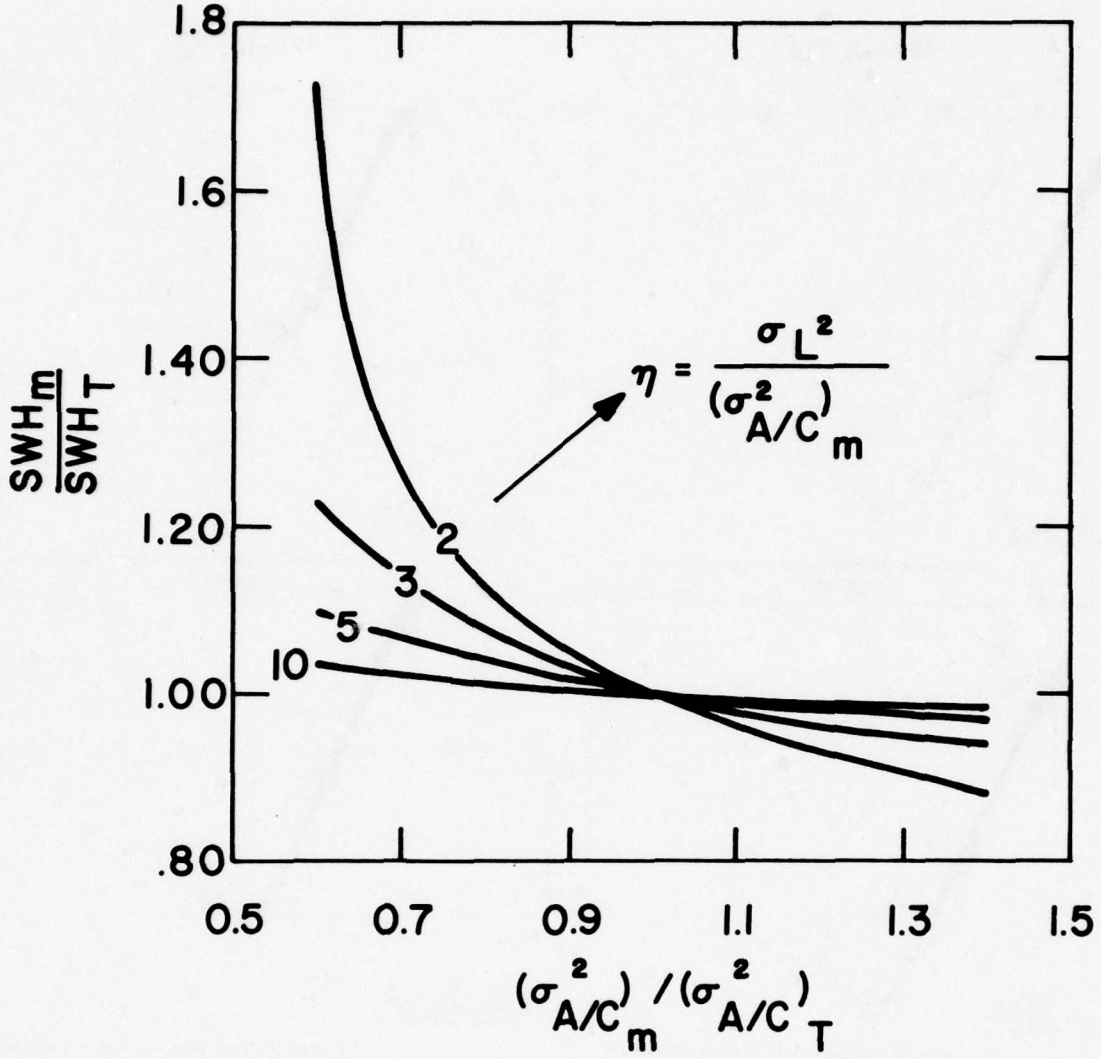


Fig. VI—15 — Effect of erroneous estimation of aircraft motion on $H_{1/3}$

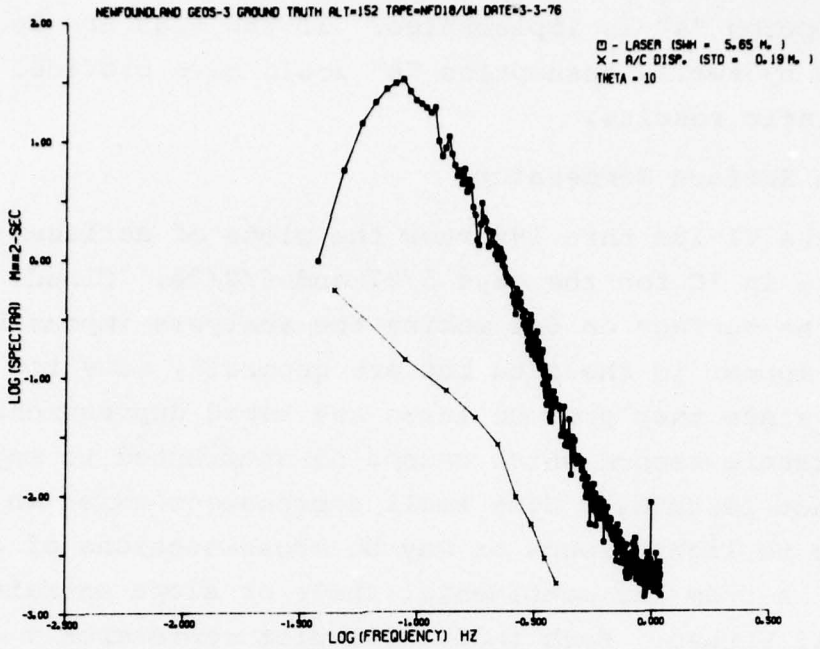


Fig. VI—16 — Wave spectra from Newfoundland GEOS-3 underflight, 3/3/76

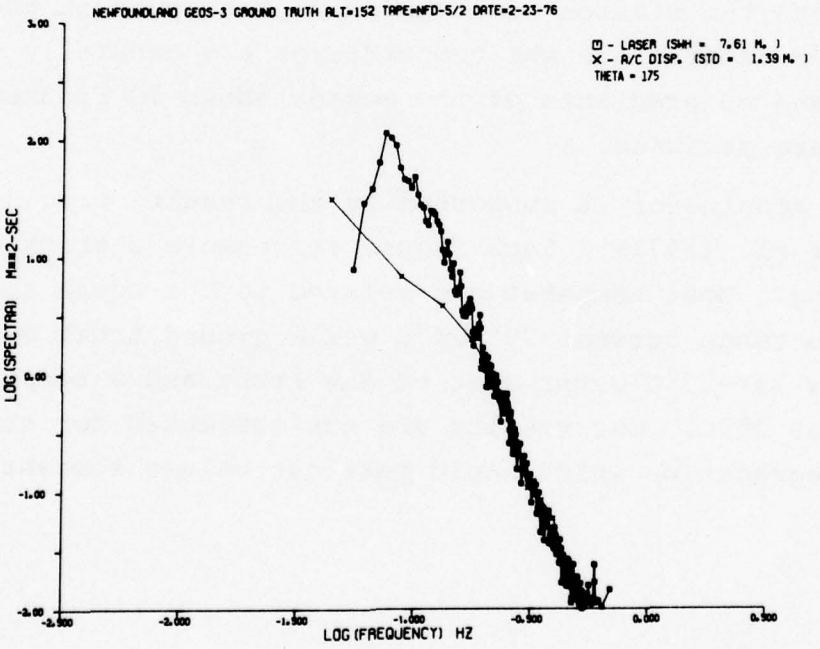


Fig. VI—17 — Wave spectra from Newfoundland GEOS-3 underflight 2/23/76

when assumption "a" is implemented. If the seas had been dominanted by swell, assumption "b" would have provided the most realistic results.

C. Ocean Surface Temperature

Figures VI-18a thru 19f show the plots of surface temperature in °C for the days 5/27 and 6/2/76. Clouds obscured the surface on 6/4 making the analysis impossible. Clouds do appear in the data but are generally easy to recognize since they produce large and rapid depressions in the temperature record which cannot be attributed to any real surface features. Some small depressions exist which may be due to light clouds or may be cross-sections of cold water bodies from the continental shelf or slope entrained by the Gulf Stream. Each individual plot represents a data file, seven of which were taken each day along the 3050 m track. Only the first six files are presented. Apparently on both days the mission was commenced just south of the Gulf Stream front since the temperatures are generally constant and no gradients of the scales shown in Figures IV-1 and 2 were measured.

This conclusion is supported by the results provided by Curtin, et al. (1978). Each figure represents a track only 7-8 km long. Most temperatures related to the ocean surface lie in the range between 20°-24°C while ground truth measurements show 16°-17°C water west of the front and a temperature maxima near 25°C. Our results are not corrected for atmospheric degradation which would make our values somewhat low.

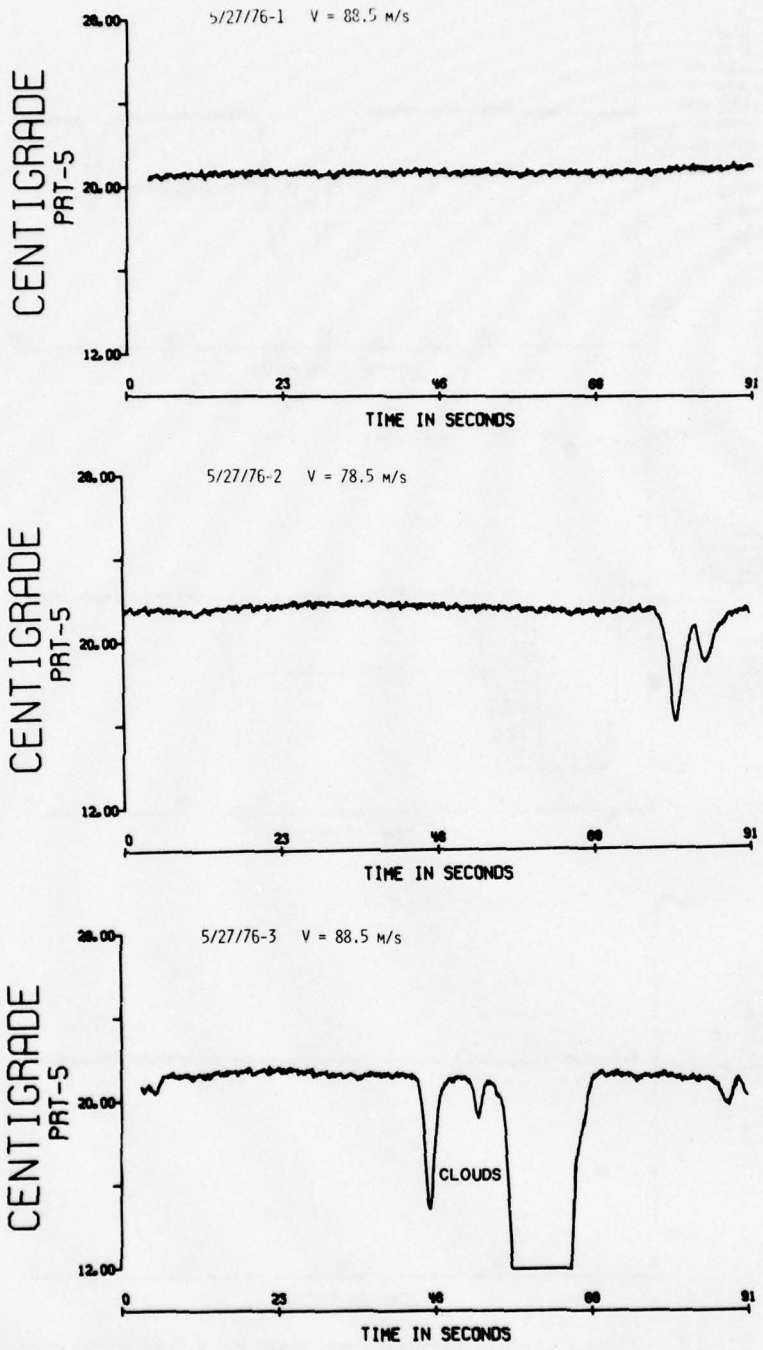
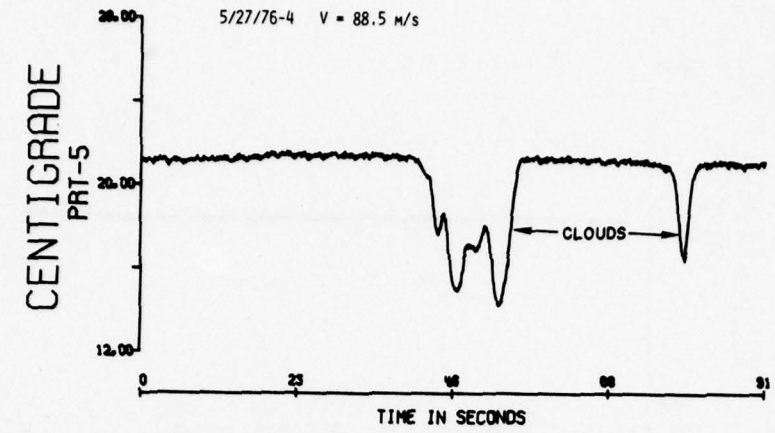
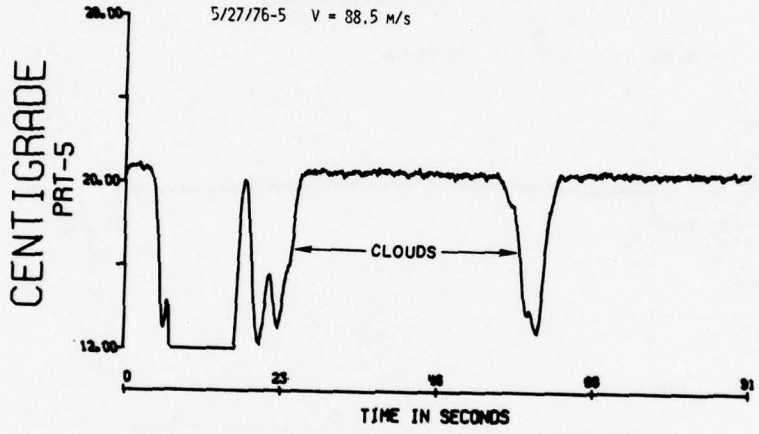


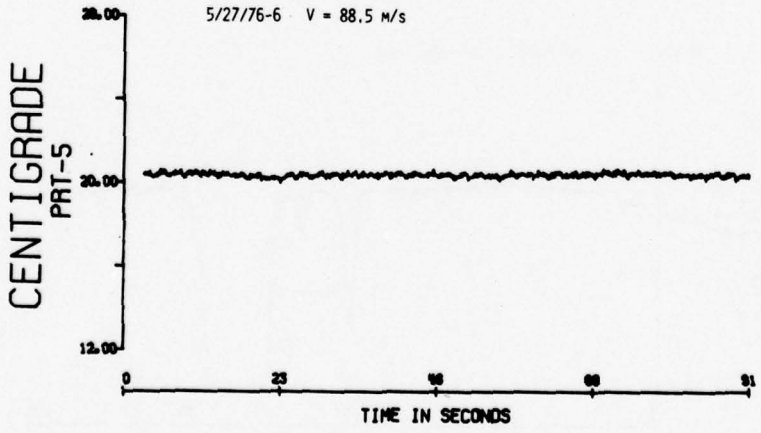
Fig. VI—18 — Ocean surface temperature from PRT-5 at 3050 meter altitude, 5/27/76 (Continues)



(d)



(e)



(f)

Fig. VI—18 — Ocean surface temperature from PRT-5 at 3050 meter altitude, 5/27/76 (Continued)

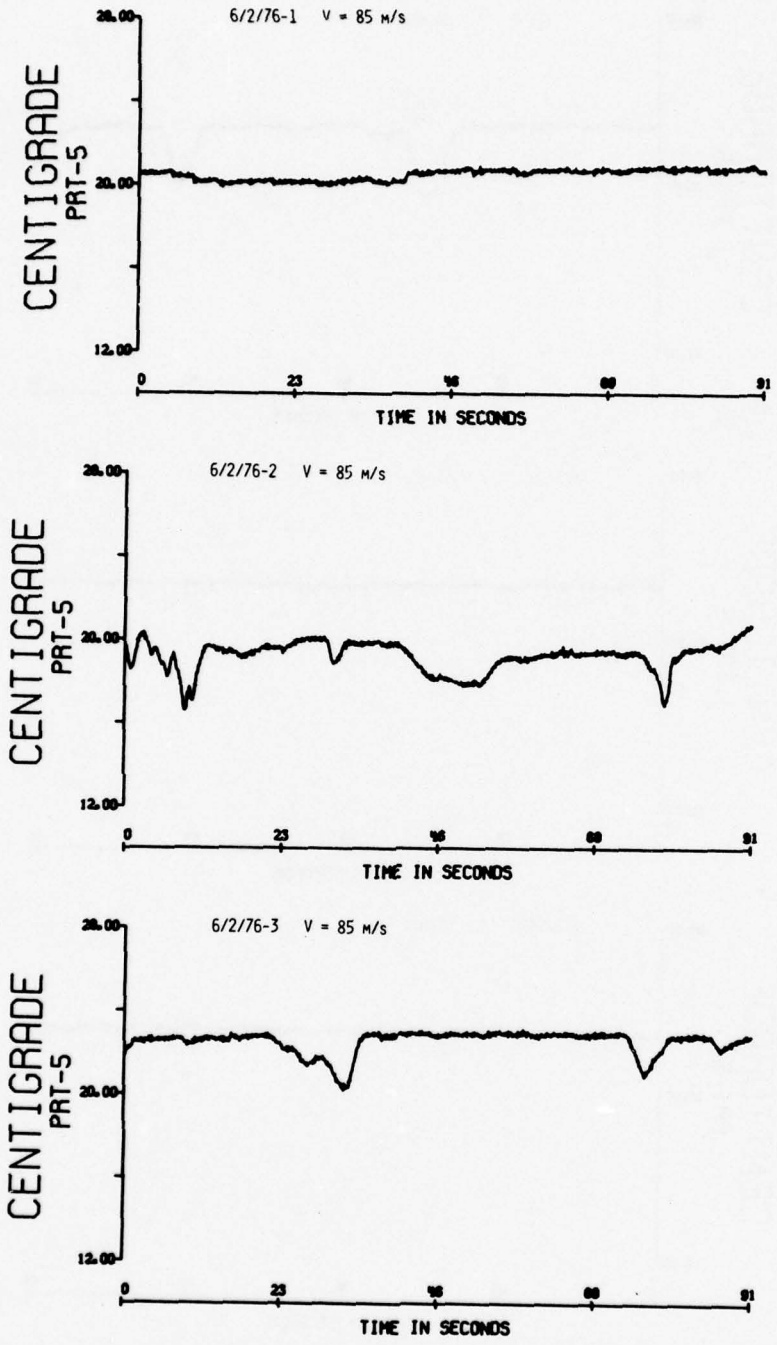
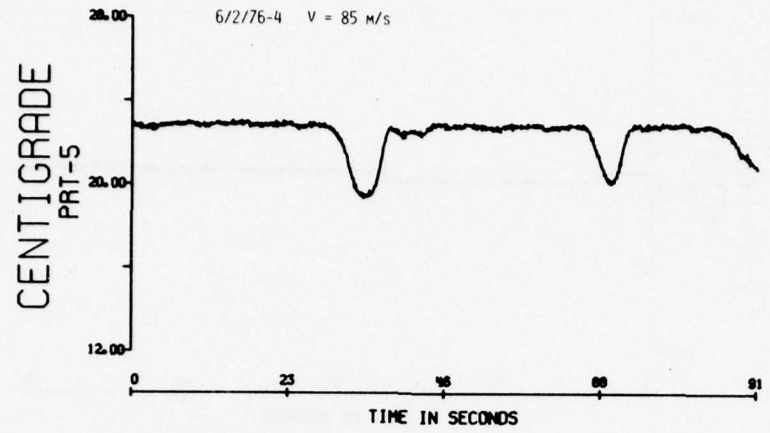
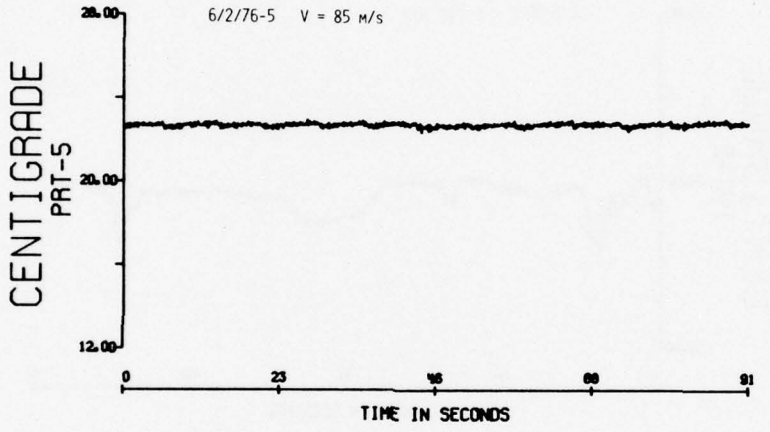


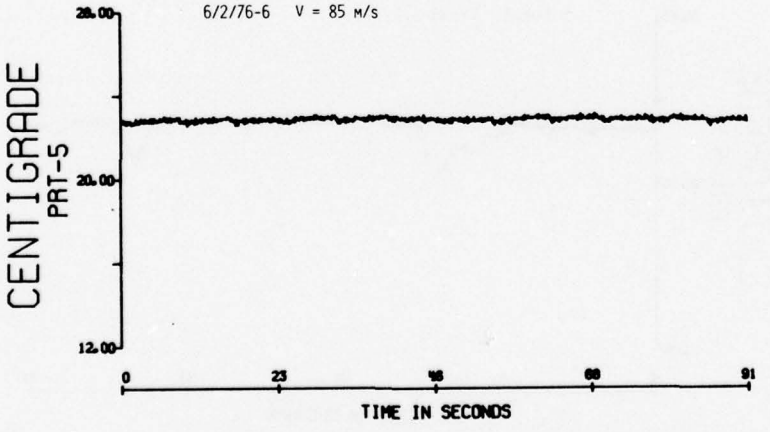
Fig. VI—19 — Ocean surface temperature from PRT-5 at 3050 meter altitude, 6/2/76 (Continues)



(d)



(e)



(f)

Fig. VI—19 — Ocean surface temperature from PRT-5 at 3050 meter altitude, 6/2/76 (Continued)

VII. SUMMARY

The results of this experiment show that the active microwave sensors (high-flight radar, wind-wave radar) provide consistent and accurate estimates of significant wave height and surface wind speed, respectively. It should be emphasized that the atmospheric conditions existing during this project were relatively calm with wind speed below 12 m/s and the sea states not higher than 4 meters. Measurements of significant wave height by the laser profilometer, in general, correlate quite well with those from the high-flight radar although comparisons between simultaneous laser and radar measurements are not possible since they operate at different altitudes. The laser estimates of SWH from individual legs of the star-patterns flown indicate that considerable spatial variability in sea state can exist at least for low sea state conditions.

Satisfactory removal of aircraft motion from the profilometer data was a major effort in this study. The approach was to filter the laser record so as to remove the low frequency components which were not coincident with the ocean surface signal, then incorporate the aircraft's vertical acceleration information for the removal of high freqeuncy contamination that did overlie the true signal obtained in the profilometer record. Examination of individual spectral estimates of the filtered accelerometer data exhibited large fluctuations in this quantity, yet the resultant significant wave height estimates remained stable. In addition, two results of profilometer data collected from another ground truth mission (Newfoundland) are provided to further establish confidence in the algorithm's performance on data sets having much more severe aircraft motion contamination and higher sea states. The results are very satisfactory. An alternative approach to aircraft motion removal is to take longer data segments which would allow an adequate estimation

of the entire aircraft motion spectrum and subtract this from the spectrum provided by the profilometer. This approach would eliminate the necessity of applying a numerical filter, but would require much longer tracks.

The effects of angular dispersion on profilometer-derived ocean wave spectra can also introduce serious problems since the flight track may not be parallel to the direction of a wave component's propagation. Experimental results show that the previous practice of assuming that all waves propagate parallel to the wind can cause more extreme spectral distortion than simply assuming that all waves travel in a direction coincident with the flight track. This is especially true when the angle between the track and the wind exceeds 30 degrees. However, this observation would not be true if the wave field were highly directional, then the previous assumption would be more appropriate. To clarify this issue, a mathematical simulation has been included which models the spectrum derived from a line-profile sample of a directional wave field. Several mathematical forms for the directional wave spectra were used and track angles of 0, 15, 30, 45, and 60 degrees to the wind were considered. The result indicates that spectral aliasing is not serious for wind-driven seas if the flight track is within 15 degrees of the wind direction. Otherwise, the distortion become more prevalent as that angle increases. This distortion may indicate a possible technique for determining the functional form of the angular spreading function. By taking airborne profilometer data at various angles to the wind simultaneously with a stationary wave profiler, various angle spreading functions could be applied to the airborne profile-derived spectra so as to shift it back upon the spectra from the stationary sensor.

Finally, the passive airborne temperature sensor, the PRT-5, produced very realistic values of the sea surface

temperature even though atmospheric corrections were not employed. The temperature range from PRT-5 lies within the domain of values supplied by in-situ measurements.

ACKNOWLEDGEMENTS

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APPENDIX A

DETERMINATION OF WIND FROM THE WIND-WAVE RADAR

The results published by Hammond, et al (1977) show how wind speed can be obtained from the return waveform of the nanosecond radar. However, the particular cases derived in that paper relate to the aircraft altitude of 150 m. It was therefore necessary to recalibrate the algorithm for an altitude of 305 m. Figures A-1 and A-2 represent the appropriate curves. Figure A-1 shows the normalized waveforms that correspond to various mean wind speeds 12.5 meters above mean sea level. The wind is related to the slope of the trailing end of the waveform and Figure A-2 plots wind speed vs slope of the trailing end. The device is particularly sensitive at low wind speeds as were experienced during the Gulf Stream flights.

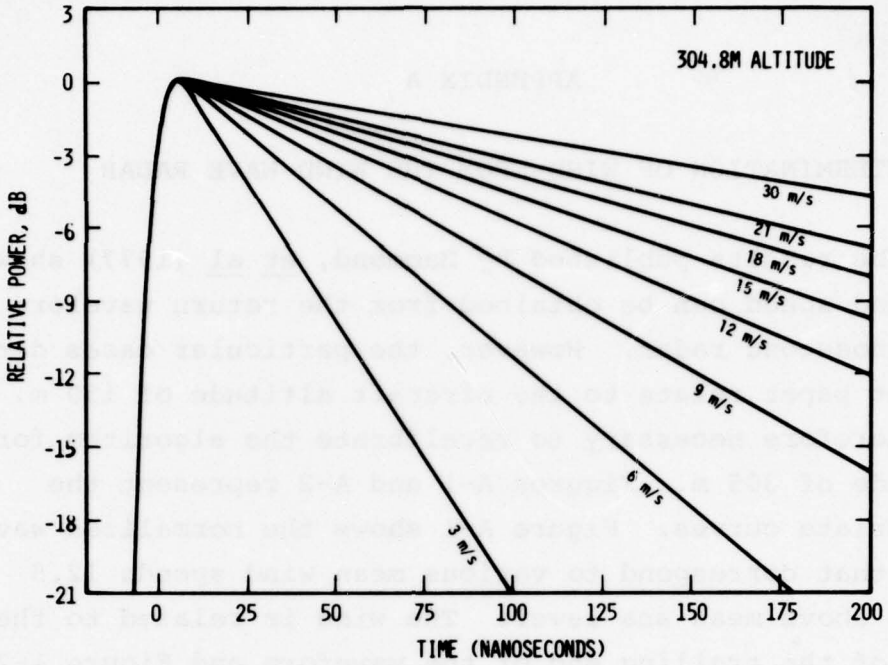

Fig. A—1 — Normalized return waveform vs. surface wind speed

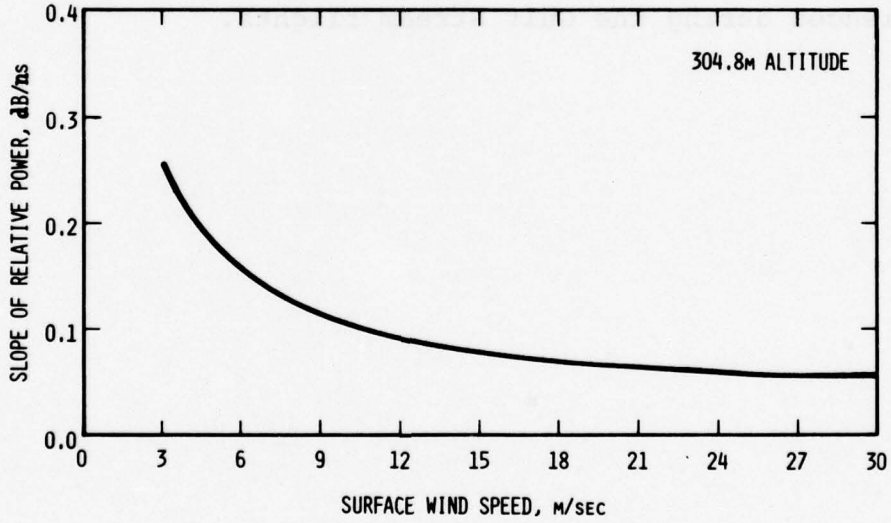

Fig. A—2 — Slope of waveform trailing end vs. wind speed

APPENDIX B

EFFECT OF LASER RESPONSE TIME

The Spectra-Physics Geodolite 3A has a selection of three response times, 5, 10, and 20 ms. The response time, τ, is defined as the time interval for the range output signal to get to 90 percent completion in response to a step change in range. Thus there is a smoothing effect on the measured profile, the severity of which is determined by the aircraft speed and the response time. During the Gulf Stream experiment, the response time, τ, was 20 ms. If the aircraft speed were 75 m/s, then the smoothing effect covered 1.5 m.

It is desirable to find a cut-off frequency, f_c, so as to determine the power gain at the Nyquist frequency, $f_f = f_s/2$. From the above information, the time constant of the laser circuit may be found.

$$0.9 = 1 - e^{-\alpha\tau} \tag{1}$$

Using $\tau = 0.02$s, α equals 115. The voltage gain, A, is given by

$$A = [1 + (\omega/\alpha)^2]^{-1/2} \tag{2}$$

where ω is the radian frequency of an input component. The standard definition of f_c corresponds to a voltage gain = 0.707.

$$0.707 = [1 + (2\pi f_c/\alpha)^2]^{-1/2} \quad (3)$$

Immediately one sees that $\alpha = 2\pi f_c$ and $f_c = 18.3$ Hz. Therefore,

$$A = [1 + (f/f_c)]^{-1/2} \quad (4)$$

The power gain, G, is of interest because distance is directly proportional to the output voltage and power spectra derived from the variance of the distance measurements is the final product. In decibels, the power gain is

$$G_{db} = 10 \cdot \log (A^2)$$

$$= -10 \cdot \log \left(1 + \frac{f}{f_c}\right) \quad (5)$$

If $f_f = 45$ Hz, then

$$G_{db} = -10 \log \left(1 + \frac{45}{18.3}\right) = -8.5 \text{ db}$$

which is the case for the analysis used in this study. The laser does serve as a low-pass filter but 8.5 db decrease is not generally considered sufficient for eliminating spectral aliasing. Fortunately, for our application, no significant energy is found at wavelengths $\approx$ (75 m/s) $\cdot$ (1/45)s < 2 m. However, if the data is digitized at slower rates, then that wavelength increases. For $f_f = 22.5$ Hz, $G_{db} = -4$ db and the corresponding wavelength would be ≈ 3.3 m. For $f_f = 11.25$ Hz, $G_b = -1.4$ db and the wavelength increases to 6.5 m. The maximum amplitude of a 6.5 m wave is approximately 0.5 m, therefore significant error could be introduced during low sea states if the data is digitized too coarsely. All of these factors should be taken into consideration when a profilometer is used.

APPENDIX C

DETERMINATION OF THETA

As discussed in Section VI, the data has been analyzed in two fashions, the analysis using assumption "b" requires the angle between the ground track and some reference direction be known in order to properly doppler shift the wave spectra. This angle, θ, (Figure II-2) can be defined and evaluated in several ways depending on which vector is used as the reference. These choices include the surface wind given by the ship or by weather maps, wind derived from the aircraft INS data and dominant wave direction provided by the ship.

Using the wind direction as a reference direction could prove troublesome since the dominant wave may be swell not correlated to the wind. This can cause a large error in the doppler shift. Since the wind direction can change rapidly in space and time due to the presence of fronts, using the wind to derive θ is not advisable in such situations. The weather patterns during the Gulf Stream experiment included several fronts as discussed in Section IV. Furthermore, use of INS-derived wind would be subject to error if the wind vector rotates with elevation. Despite these objections, wind vectors from the INS data were derived for each leg of each star pattern on the 6/2/76 and 6/4/76 flights. The INS provided the aircraft heading, ground track, true air speed, ground speed and drift angle. The vector analysis was not made on 5/27/76 data because

the aircraft true air speed was not recorded by the INS operator. The best way of utilizing these vectors is to average the individual estimates over the five legs to obtain a mean wind for the star pattern. The individual vectors showed a great deal of scatter, particularly in direction. The data on 6/2/76 produced extremely scattered wind directions where a maximum difference of 138° within one star pattern existed. The INS was not operating properly that day and Loran-A data was collected as an alternative. The individual vectors from the star patterns of 6/4/76 were much more consistent for both star patterns. The mean wind vectors from the two star patterns had the headings 214° and 225° while the ship reported wind and dominant wave direction was 225°. Therefore on 6/4/76, all values of θ were derived using 225° as the reference heading. For the reasons stated above, the dominant wave direction was used in defining θ even when the direction differed from the wind direction as it did on 5/27 ($\approx$40-45° misalignment reported by the ship). Also, ground tracks derived from the Loran A information were used on 6/2. Table C-1 presents the final values of θ.

TABLE C-1

VALUES OF THETA

Day	Pattern/ Leg	Ground Track	Dominant Wave Heading	True θ	Design θ
5/27/76	2/1	169.4	225	124.4	180
	2/2	283.7	225	238.7	300
	2/3	41.6	225	356.6	60
	2/4	134.1	225	89.1	150
	2/5	11.2	225	326.2	30
	5/1	161.5	220	116.5	180
	5/2	281.1	220	236.1	300
	5/3	50.6	220	10.6	60
	5/4	141.6	220	101.6	150
	5/5	20.5	220	340.5	30
6/2/76	2/1	0	40	140	180
	2/2	94	40	234	300
	2/3	240	40	20	60
	2/4	338	40	119	150
	2/5	192	40	336	30
	5/1	64	40	204	180
	5/2	210	40	313	300
	5/3	261	40	41	60
	5/4	13	40	153	150
	5/5	258	40	38	30
6/4/76	2/1	268.0	225	223.0	180
	2/2	39.3	225	354.3	300
	2/3	160.8	225	115.8	60
	2/4	242.7	225	197.7	150
	2/5	134.8	225	89.8	30
	5/1	232.0	225	184.0	180
	5/2	345.0	225	300.0	300
	5/3	128.2	225	83.2	60
	5/4	209.5	225	164.5	150
	5/5	93.2	225	48.2	30

APPENDIX D

EFFECT OF ERRONEOUS ESTIMATION OF AIRCRAFT MOTION ON $H_{1/3}$

In this appendix, the derivation of η in Figure VI-21 is given. The subscripts "m" and "T" stand for "measured" and "true" respectively. The symbol, σ^2, is the variance and the subscript "L" implies "laser and "A/C" relates to the aircraft motion.

$$(H_{1/3})_T = 4\left[\sigma_L^2 - (\sigma_{A/C}^2)_T\right]^{1/2}$$

$$(H_{1/3})_m = 4\left[\sigma_L^2 - (\sigma_{A/C}^2)_m\right]^{1/2}$$

$$\nu = \frac{(H_{1/3})_m}{(H_{1/3})_T} = \left[\frac{\sigma_L^2 - (\sigma_{A/C}^2)_m}{\sigma_L^2 - (\sigma_{A/C}^2)_T}\right]^{1/2}$$

If $\eta = \sigma_L^2/(\sigma_{A/C}^2)_m$, and $\varepsilon = (\sigma_{A/C}^2)_m/(\sigma_{A/C}^2)_T$, then

$$\nu = \left\{\frac{\varepsilon(\eta-1)}{\varepsilon\eta-1}\right\}^{1/2} .$$

Thus the ratio of measured to true SWH is a function of the relative size of the measured aircraft motion to the true aircraft motion and the ratio of the laser measurement to the measured aircraft motion. Figure VI-21 presents the family of curves for η = constant.

APPENDIX E

EFFECTS OF WAVE DIRECTIONALITY ON LINE-PROFILE DERIVED SPECTRA

We will simulate analytically the frequency spectrum that would be obtained by using surface elevation data taken by a profilometer moving in a straight line. Angular dispersion in the wavefield will affect our results. The wave number of any wave component will be alaised in the manner indicated in Figure E-1. Please note that the θ defined in Figure E-1 is not related to the θ defined in Figure II-2 of the main text and is used here in order to be consistent with most of the literature describing angular dispersion of ocean waves. To derive a unique quantitative result is not possible since no single form for the directional wave spectrum has been proven to be superior to other proposed expressions found in the literature. Therefore, we will select a model spectrum from the literature that yields qualitative answers to this question.

The directional wave spectrum is generally written as the product of a frequency-dependent angular spreading function, $H(\sigma,\theta)$, and a frequency dependent function.

$$\Phi(\sigma,\theta) = H(\sigma,\theta)\phi'(\sigma) \qquad (1)$$

This form has been suggested by many investigators including Longuet-Higgins (1962) and more recently Ou, et al. (1974), but insufficient data exists to really specify $H(\sigma,\theta)$. More often a simplified version, $h(\theta)$, is used. On

the assumption that wave energy should be distributed symmetrically about the wind vector, $h(\theta)$ is usually chosen to be a cosine function raised to some power or a summation of such terms. Indeed, Krylov, et al. (1966) has indicated $h(\theta) \propto \cos^2 \theta$. Therefore, we will use the following functions:

$$h(\theta) = B(n) \cos^{2n} \theta = \begin{cases} \pi^{-1} \text{ Isotropic} & n=0 \\ (2/\pi) \cos^2 \theta & n=1 \\ (8/3\pi) \cos^4 \theta & n=2 \end{cases} \quad (2)$$

where

$$B(n) = \left(\int_{-\pi/2}^{\pi/2} \cos^{2n} \theta \, d\theta \right)^{-1} .$$

$B(n)$ represents a normalization factor which ensures the conservation of energy.

The equations developed below are general in that θ' (see Figure E-1) may assume any value within the domain $[-\pi/2, \pi/2]$. The relationship between $\phi'(\sigma)$ and the frequency spectrum, $\phi(\sigma)$, is found by integrating $\Phi(\sigma,\theta)$ with respect to θ and $\phi'(\sigma) = \phi(\sigma)/\sigma$. A similar relationship holds in wave-number space, $S'(k) = S(k)/k$.

The Pierson-Moskowitz (P-M) spectrum will be used for $\phi(\sigma)$.

$$\phi(\sigma) = \frac{\alpha g^2}{2\sigma^5} \exp \left(-\beta \frac{g}{U \cdot \sigma} \right)^4 \quad (3)$$

where g is the gravitational acceleration, U is the surface wind speed at 19.5 meters and α and β are 4.05×10^{-3} and 0.74 respectively.

Since the aliasing problem deals with spatial rather than temporal frequencies, $\phi(\sigma)$ is transformed to $S(k)$ via

the dispersion relationship, $\sigma^2 = gk$.

$$S(k) = \frac{\alpha}{2k^3} \exp\left(-\beta \frac{g}{U^2 k}\right)^2 \tag{4}$$

The directional wave number spectrum may be written in a form analogous to (1) .

$$\Psi(k,\theta) = \frac{\alpha h(\theta)}{2k^4} \exp\left(-\beta \frac{g}{U^2 k}\right)^2 \tag{5}$$

From Figure E-1, the apparent wave number, k_a, is related to the true wave number by

$$k_a = k \cos \gamma, \tag{6}$$

and therefore,

$$S_a(k_a) = S(k) \sec \gamma. \tag{7}$$

Substituting (2), (6), and (7) into (5),

$$\Psi_a(k_a,\theta) = h(\theta) \cdot S'_a(k_a)$$

$$= \frac{A}{k_a^4} \cos^{2n}(\theta'+\gamma) \cos^3\gamma \exp\left(\frac{-\nu\cos^2\gamma}{k_a^2}\right), \tag{8}$$

where $A = \alpha B(n)/2$ and $\nu = \beta g^2/U^4$. It should be noted that $\theta' + \gamma = \theta$ for all cases only when γ is defined as the angle measured from the flight track to the wave ray. To obtain the desired result, $S_a(k_a)$, (8) must be integrated over the coordinate plane from $\theta = -\pi/2$ to $\pi/2$. Because θ' = constant for a particular track, $d\theta = d\gamma$. Thus,

$$S_a(k_a,\theta') = \int_{-\pi/2}^{+\pi/2} \Psi_a(k_a, \theta',\gamma)\, k_a\, d\gamma \qquad (9)$$

and the apparent wave number spectrum retains an additional dependence on θ'. At this point, specific values of n must be substituted into (8) in order to determine (9). The results involve modified Bessel functions $I_j(\zeta)$ where $\zeta = \beta(g/U^2k_a)^2/2$ and the integrals are given by Olver (1964) after having been simplified to the appropriate forms. It should be remembered that these functions are even when j is an even integer and odd when j is odd. The expressions for the apparent wave-number spectra are

$$S_a(k_a,\theta') = \begin{cases} \dfrac{\alpha e^{-\zeta}}{4k_a^3}\,(I_o(\zeta) - I_1(\zeta)) & n=0 \\[2ex] \dfrac{\alpha e^{-\zeta}}{8k_a^3}\left[(2+\cos 2\theta')\cdot I_o(\zeta) - 2(1+\cos 3\theta')\cdot I_1(\zeta) + \cos 2\theta'\cdot I_2(\zeta)\right] & n=1 \\[2ex] \dfrac{\alpha e^{-\zeta}}{24k_a^3}\left[2(3+2\cos 2\theta')\, I_o(\zeta) - (8\cos 2\theta' + \cos 4\theta' + 6)\cdot I_1(\zeta) + 2(\cos 4\theta' + 2\cos 2\theta')\cdot I_2(\zeta) - \cos 4\theta'\cdot I_3(\zeta)\right] & n=2. \end{cases} \qquad (10)$$

In order to present the results in a form that generally appears in the literature, we have transformed $S_a(k_a,\theta')$ back to the frequency domain and nondimensionalized those expressions in the same manner as Pierson and Moskowitz (1964). The transformation is given by

$$\phi_a(f_a,\theta') \frac{g^3}{U^5} = \frac{4\pi g^3}{U^5} \left(\frac{k_a}{g}\right)^{1/2} \cdot S_a(k_a,\theta') \; . \qquad (11)$$

Figures E-2 thru E-6 show the apparent frequency spectra for various track angles relative to the dominate wave direction. The P-M spectra is plotted as a reference and the isotropic case is included because it is the limiting case as directionality decreases. Several trends can be seen: the spectral peak shifts to lower frequencies for larger values of θ'; the peak broadens and decreases monotonically as θ' increases; the slope of the high frequency portion of the apparent spectrum does not dramatically deviate from that of the P-M spectrum until large values of θ' are reached; the difference between the $\cos^2\theta$ and $\cos^4\theta$ directionality models is not particularly strong until θ' exceeds 45 degrees. The spectral distortion is not severe for track angles within 15 degrees of the wind vector. These indicate that airborne profilometer data is still useful for wind-wave generation studies as long as close attention is given to the track angle relative to the dominate surface wave direction. Also, the proposition of using spectra from various track angles to infer $h(\theta)$ does not appear promising because the spectra do not show a substantial enough variation with $h(\theta)$.

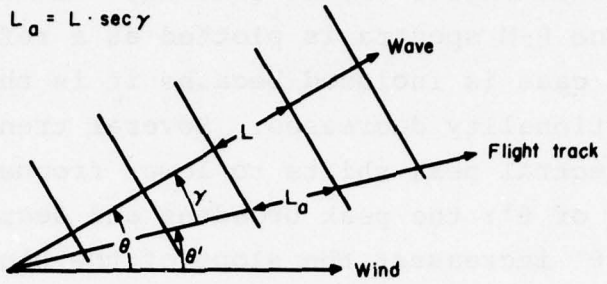

Fig. E—1 — Airborne profilometer measurement of wavelength

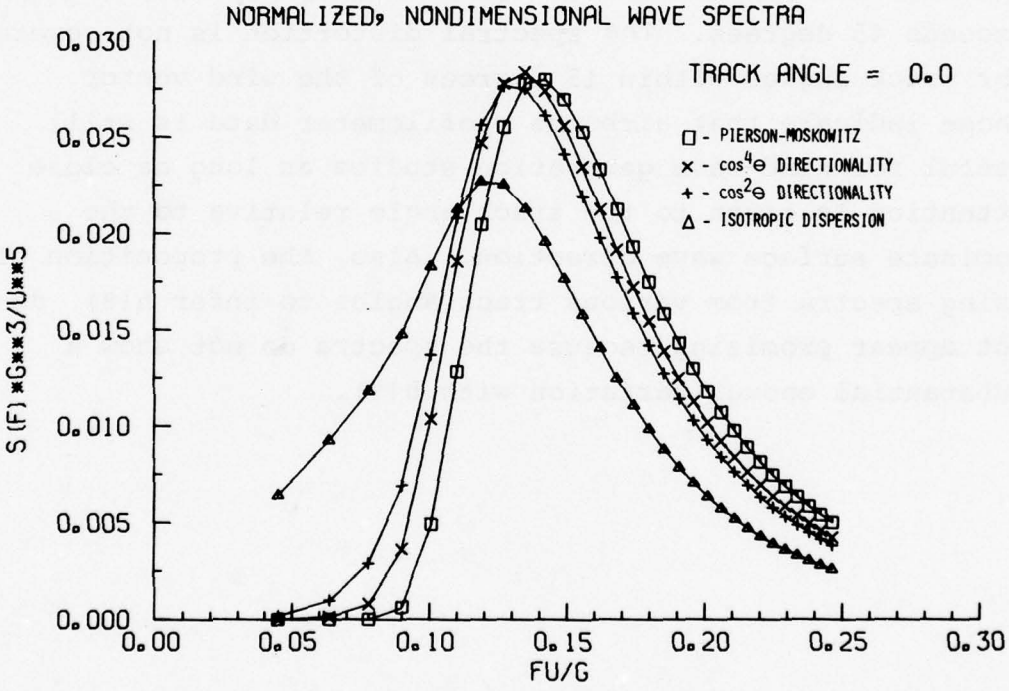

Fig. E—2 — Aliased spectrum for $\theta' = 0°$

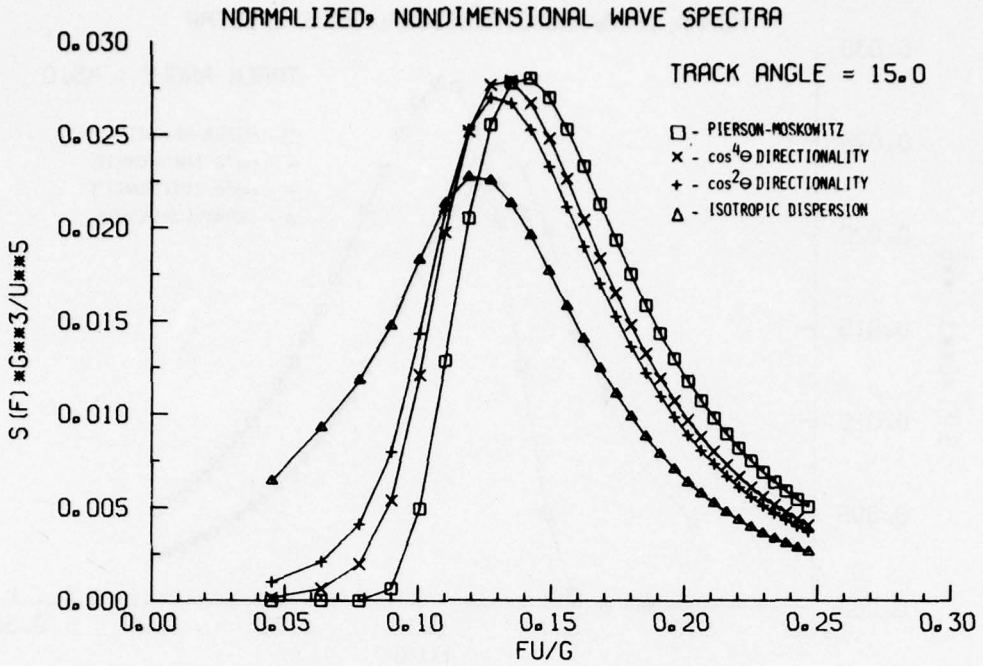

Fig. E—3 — Aliased spectrum for $\theta' = 15°$

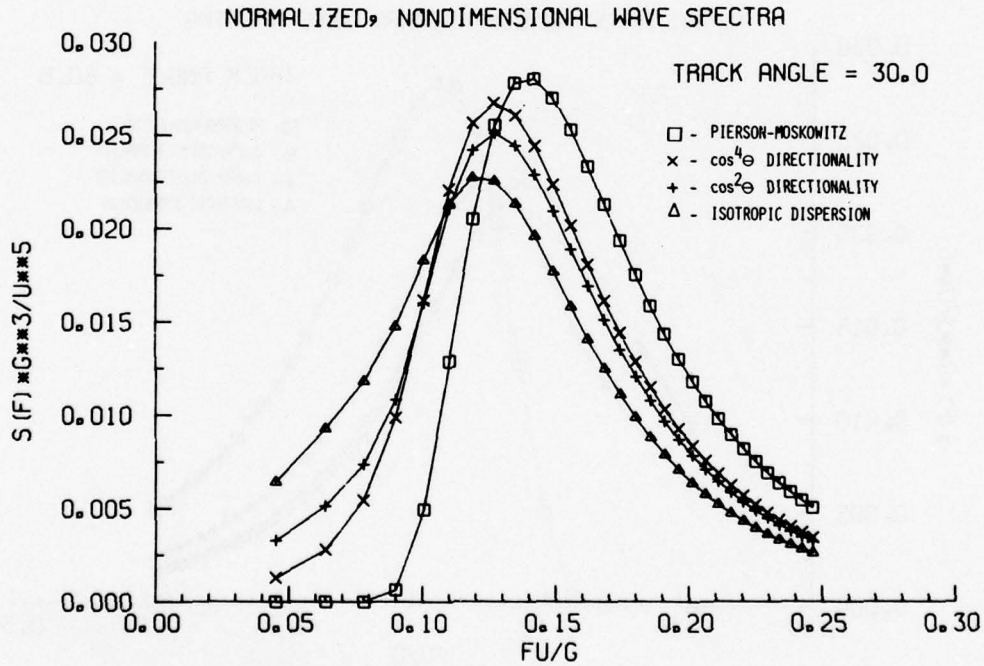

Fig. E—4 — Aliased spectrum for $\theta' = 30°$

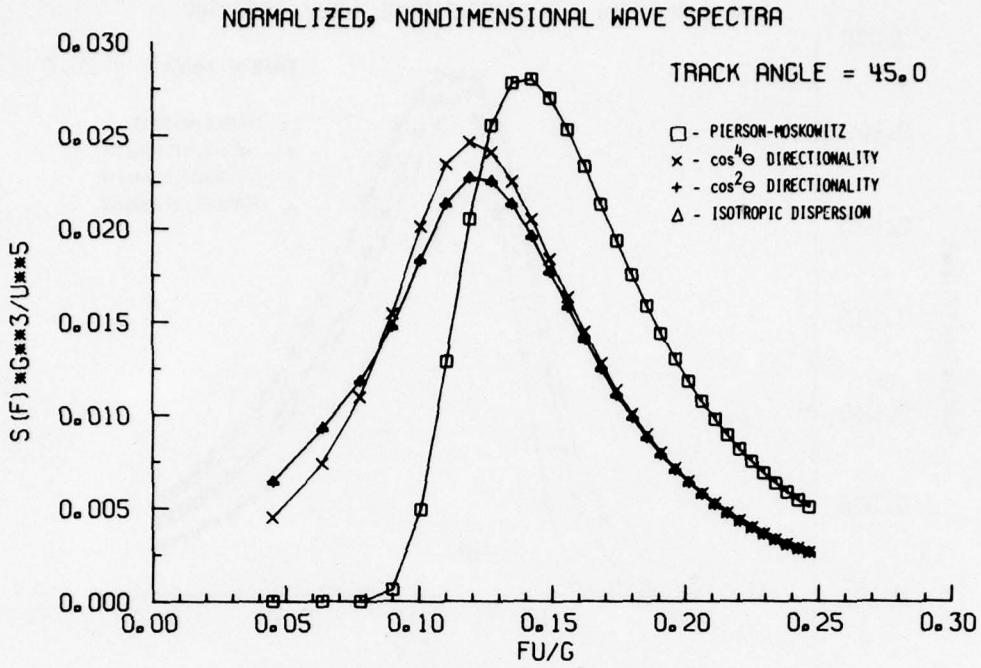

Fig. E—5 — Aliased spectrum for $\theta' = 45°$

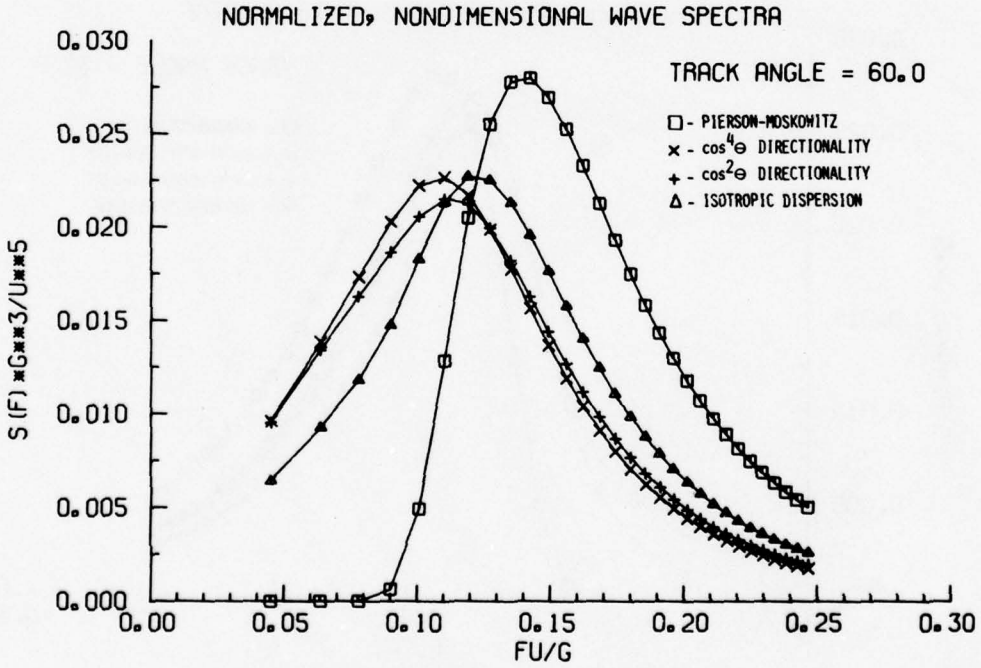

Fig. E—6 — Aliased spectrum for $\theta' = 60°$

APPENDIX F

AIRSPEC 5


```
W=  00  PRINT,/110,MCC_AIN,S
W=  00  EQUIP,1=**,HI,40
W=  00  EQUIP,5=**,HY,80
W=  00  EQUIP,10=**,HI,RW
W=  00  FTN,X,L
      PROGRAM AIRSPEC5
      DIMENSION   Y(8192),Z(8192),ASQ2NU(4097,2)
      DIMENSION FQRESF(5),FRFACTOR(5)
      DIMENSION  PLTARRAY(1026),IM(2),Q(8194)
      DIMENSION FNUMT(4097,2)
      DIMENSION FREQSPEC(4097,2), HBARF(2)
      DIMENSION S(1025)
      DIMENSION   LPH1(10),IS1(2),IND(2),DFNC(301,2)
      DIMENSION   FILT(257),WEIGT(257),IFILT(3)
      DIMENSION  DEVN(301),LABOVE(2),LBELOW(2)
      DIMENSION                  NGSPEC(15),EMAX(2),FBAR(2),SPECAVGN(2)
      COMMON/A/Y,Z
      COMMON/RDTAPE8/LFILE(7),KFILE,IFILE,MFILE
      COMMON/UNPACKR/RAD(100),CHAN(7),AINSS(8),INCODE(8),NFILE,
     1NDAY,MONTH,NYR,NHR,MIN,ALT,DDOT,NHSCOPE,NVSCOPE,VSCALE,ISWEEP
      COMMON/SPANPEN,DELT,PLTSPACE
      COMMON/3/DFNC
      COMMON/B/J(5500,2),FNUMTF(4097,2)
      EQUIVALENCE  (Q,FNUMT),(FILT,WEIGT),(U,FNUMTF)
      TYPE  REAL   KURTOSIS,LABOVE,LBELOW
      TYPE INTEGER   PRINT,PHAS,PLTON,THETA
      DATA (IFILT = 8H     LOW,8H    HIGH,8H      NO)
      DATA((FRFACTOR(MP),MP = 1,5)= 1.,0.5,0.63,0.15,0.05)
C
C     NOS = NUMBER OF SAMPLES
C     IM(1) = NUMBER OF POINTS IN FAST FOURIER TRANSFORM
C     IM(2) = POWER OF 2 FOR IM(1)
C     ISEC = NUMBER OF DATA SAMPLES FROM WHICH ONE DATA POINT IS
C            SELECTED FOR SPECTRAL ANALYSIS
C     XMAXVL = MAXIMUM VALUE OF FREQUENCY FOR PLOTTING SPECTRA
C     DELT = SAMPLE INTERVAL CALCULATED FROM THE SPEED OF THE TAPE
C        RECORDED
C     V = AIRCRAFT GROUND SPEED IN KNOTS, IF = 0, NO DOPPLER SHIFT, IT
C         SHOULD BE NOTED THAT CONST CONTAINS A DIVISION BY V.
C     W = WIND SPEED IN METERS/SEC
C     IFILDAT=1, FILTERED DATA IS RECORDED ON OUTPUT TAPE
C     CUT = CUT-OFF FREQUENCY/SAMPLING FREQUENCY
C     H = FILTER SLOPE OF WEIGHTS
C     NUMFT = NUMBER OF FILTER WEIGHTS,  2N+1=NUMBER OF PTS IN FILTER.
C     LOWHI = LOW PASS FILTER = 1, HIGH PASS FILTER = 2.
C        NO PASS FILTER = 3
C     NAVGL = SAME AS NOS
C     LPH1 = TITLE OF THE RUN
C     FREQSPEC=AVG SPECTRUM OF TOTAL NUMBER OF SPECTRA COMPUTED
C     PLTON= 0, SPECTRA ARE CALCULATED,  LISTED IN OUTPUT AS PLOT.
C     SWHONLY=1,0, SWH IS THE ONLY QUANTITY DERIVED FROM FFT ESTIMATES
C     WHDIST=0.0, PLOT WAVE HEIGHT DISTRIBUTION
C     NOWAVPLT=1, NO HISTOGRAMS.  LISTED IN OUTPUT AS WAVE PL.
C     NUMHIST= 1(LASER HISTOGRAM PLOTTED), =2(ACCELERATION PLOTTED ALSO)
C     N1=1, PLOT FREQSPEC
C     N2 = 1 INCORPORATES ANGULAR SPREADING INTO DOPPLER SHIFT
C     N3=1, A/C DISPL SPECTRUM IS REMOVED FROM LASER SPECTRUM
C     IPAUSE = 0 = NO MACHINE PAUSE, = ANY OTHER INTEGER = PAUSE, 6600
C     PRINT = 0 PRINT = 0, NOT TO PRINT = 1
```

```
C      PHAS = NOT TO REMOVE PHASE SHIFT = 0. TO REMOVE PHASE SHIFT = 1
C      IPLOTSP= ), SPECTRA (ASQ2NU) ARE PLOTTED
C      NRECSKP = NUMBER OF FILES TO SKIP ON OUTPUT TAPE FILES
C      NPEN = CODED NUMBER FOR COLOR PENS OF THE PLOTTER
C      NREC = NUMBER OF RECORDS PER FILE ON INPUT TAPE
C      LI = INPUT TAPE
C      LO = OUTPUT TAPE
C      PLTSPACE=PARAMETER IN PLOT2, IT EQUALS INCHES PER DELT,
C      MTREW = TO REWIND INPUT TAPE = 1, NOT TO REWIND INPUT TAPE = 0
C      THETA = ANGLE IN DEGREE BETWEEN GROUND TRACK AND MEAN WIND
C         DIRECTION
C      QP = LASER RANGE SCALE
C      DFLASER = CONVERSION COEFFICIENT FOR LASER CORRESPONDING TO QP .
C                IT IS SET NEGATIVE TO INVERT THE LASER PROFILE,
C      DF = CONVERSION COEFFICIENT FOR ACCELEROMETER
C      NSPECAVG = NUMBER OF SPECTRA TO BE AVERAGED TOGETHER PER FILE
C      NGSPEC = NUMBER OF SPECTRA IN SEQUENTIAL NUMBER WHICH ARE NOT TO
C         BE AVERAGED
C      TSPECAVG=TOTAL NUMBER OF LASER SPECTRA DERIVED TO YIELD FREQSPEC.
C      VSHIP = SHIP SPEED IN FEET/SEC
C      NF = NUMBER OF FILES TO BE UNPACKED
C      NLC = NUMBER OF THE LASER CHANNEL
C      NAC = NUMBER OF THE ACCELERATION CHANNEL
C      LFILE = PARAMETER DETERMINING WHICH FILES ARE UNPACKED
C      KFILE = NUMBER OF FILE INPUT TAPE  IS POSITIONED TO READ
C      ISWEEP = NUMBER OF SWEEPS PER RECORD
C      NFLAG = PARAMETER DETERMINING NO. DATA PTS./SWEEP TO BE UNPACKED
C      NSETS=TOTAL NUMBER OF DATA SETS TO BE ANALYZED SEPARATELY.
C      RESTART = 1.00 INDICATES THAT COMPUTATIONS ON A DATA SET
C              (WHICH MAY BE COMPOSED OF SEVERAL FILES)ARE FINISHED AND
C              THAT REINITIALIZATION OF PARAMETERS FOR NEXT DATA SET
C              MUST BE DONE.
C
 9001 FORMAT (3I5,F10.7,F5.0,2F10.5,4I5,F10.5)
 9002 FORMAT (10A8)
 9003 FORMAT (15I5)
 9004 FORMAT ( //,20X,*THE CONTROL CARDS FOR THE NEXT FILE ARE,.*,//,10X
     *,*ON CONTROL CARD 1 -*,//,5X,*NUS*3X,*IM(1)*3X,*IM(2)*6X,*DELT*6X,
     **V*5X,*CUT*8X,*H*4X,*NUMPT*3X,*LOWHI*6X,*NF*3X,*NAVGL*4X,*DF*,/,3I
     *8,F10.7,F8.2,2F10.5,4I8,F10.5,//,10X,*ON CONTROL CARD 2 * LABEL IN
     * 80 COLUMNS*//2X,10A8//10X*ON CONTROL CARD 3 -*//6X*N1*6X*N2*3X*PA
     *USE*3X*PRINT*3X*PHASE*4X*PLOT NRECSKP WAVE PL*5X*PEN*2X*SP AVG*,1X
     *,*IPLOTSP*//1118//10X*ON CONTROL CARD 4 -*//3X*NUM REC*3X,
     *    7HLU INPT,4X,*LU OUT*3X,12HPLOT2 PT INT,6X,4HMTRW,8X,2HQP,5X,
     **THETA*,  3X,*DF LASER*//, I10,      2I10,F15.8,I10,F10.0,I10,F10.
     *3,//)
 9006 FORMAT (*)      DATA FILE CONTAINED *I5,* SAMPLES*/)
 9007 FORMAT (* *,5X,*MAX VALUE = *,F8.2,5X,*MIN VALUE = *,F8.2)
 9008 FORMAT (1H1,59X,14HPOWER SPECTRUM//20X,12HTHIS RUN IS ,10A8,/,15X,
     *16HNUMBER OF ORS  =,I6,50X,14HDATA FACTOR = ,F10.5,/,15X,16HNUMBER
     * OF LAGS =I6,50X,*CUT*9X,*= *F9.4,/15X,*DELTA TIME*5X,*=*F14.7,42X
     **SLOPE*7X,*= *F9.4,/15X*A/C VELOCITY*3X,*=*F11.4,45X*WEIGHTS*5X,*=
     * *I4,/15X*VARIANCE(1)    =*F11.4,45X*H 1/3 (1)   = *F9.4,/15X*VARI
     *ANCE(2)    =*F11.4,45X*STD DEV A/C = *F9.4,/49X,A8,* PASS FILTERED
     **/)
 9009 FORMAT (* APPARENT     VARIANCE      APPARENT      CIRC     TRUE CIRC
     *     TRUE      TRUE FREQ       TRUE      TRUE WAVE*/*    FREQ*19X,*FRE
     *Q SPEC      FREQ     FREQ SPEC      FREQ      SPECTRUM        WAVE
     *  NUMBER*/63X,*HZ*,20X,*NUMB       SPECTRUM*//)
 9010 FORMAT(1H1,4X,*FREQ(HZ)    VARIANCE   FREQ SPEC   CIRC FREQ   CIRC
```

```
     * FREQ SPEC*,//)
 9011 FORMAT(4E12.4,E17.4)
 9012 FORMAT (140,//,5X,*IST(*,I1,*) = *,I5,5X,*IND(*,I1,*) = *,I5,/,5X,
     **CENTROID = *F10.4,/5X*STD DEV  = *F10.4,/5X*SKEWNESS = *F10.4,/5X
     **KURTOSIS = *F10.4)
 9014 FORMAT (3I5,          F10.8,I5,F5.0,I5,F6.0)
 9015 FORMAT (2513)
 9016 FORMAT (*)*)
 9018 FORMAT (*)      SELECT EVERY *,I2,* SAMPLES*/)
 9019 FORMAT(* *,F7.2,2X,E12.4,2X,E12.4,2X,F6.2,2X,E12.4,2X,F6.3,2X,
     1E14.4,2X,F6.3,2X,E14.4,4X,F10.4)
 9020 FORMAT(F10.2,4I5,2F5.1,I5)
 9021 FORMAT(//,2X,*WIND SPEED*,3X,*NLC*,3X,*NAC*,3X,*NS*,3X,*NUMHIST*,
     2 2X,*SWHONLY*,3X,*WHDIST*,3X,*IFILDAT*)
 9022 FORMAT(F9.2,I8,3I6,2F10.1,I10)
 9023 FORMAT(10I8)
 9024 FORMAT(//,3X,*KFILE*,2X,*LFILE1*,2X,*LFILE2*,2X,*LFILE3*,2X,
     2*LFILE4*,2X,*LFILE5*,2X,*LFILE6*,2X,*LFILE7*,2X,*ISWEEP*,3X,
     3*NFLAG*)
 9025 FORMAT(/,5X,*HBARF(1)=*,F7.3,5X,*HBARF(2)=*,F7.3,5X,*TSPECAVG=*,
     2F3.0,/)
 9026 FORMAT(/,5X,*FILTERED DATA ON OUTPUT TAPE*,/)
 9027 FORMAT(2X,*RESTART = *,F3.1)
 9028 FORMAT(I5)
 9029 FORMAT(1H1,2X,*NSETS =*,I3,5X,*NREPEAT =*,I3)
 9030 FORMAT(///,5X,*APPARENT FREQ*,5X,*A/C SPEC*,5X,*TRUE FREQ*,5X,
     2  *WAVE SPEC*)
 9031 FORMAT(8X,F6.3,7X,E10.4,6X,F6.3,6X,E10.4)
 1925 FORMAT(/,2X,*Y(IR) = *,15X,*Z(IR) = *)
 1926 FORMAT(10X,F8.4,15X,F8.4)
 1927 FORMAT(39X,*T1*,8X,*T2*,8X,*T3*,8X,*T4*,8X,*T5*)
 1928 FORMAT(/,3X,*FREQUENCY RESPONSE FUNCTIONS = *,5F10.5,/)
 1929 FORMAT(/,3X,*AVGY =*,F8.3,10X,*AVGZ =*,F8.3,//)
 1930 FORMAT(/,3X,*SPECAVGN(1) =*,F5.2,5X,*SPECAVGN(2) =*,F5.2)
 1933 FORMAT(3X,*YS=*,F10.6,5X,*ZS=*,F10.6)
 1934 FORMAT(2X,*U(1,1) =*,F9.6)
 1935 FORMAT(2X,*U(1,2) =*,F9.6)
 1936 FORMAT(2X,*I =*,I4,5X,*U(I,1) =*,E10.3,5X,*U(I,2) =*,E10.3)
      PAUSE 1
      CALL PLOTS(PLTARRAY,1026,1)
      CALL FACTOR(1.)
C     ONLY ONE DATA CARD FOR NSETS IS NEEDED FOR EACH RUN.
      READ 9028, NSETS
C     IF ANY NEW TAPES ARE NEEDED WHEN NREPEAT CHANGES VALUE, SET
C       IPAUSE = 1 IN PREVIOUS FILES/S DATA DECK.
      DO 6900 NREPEAT = 1,NSETS
C
C     INITIALIZE PARAMETERS
C
      IM2PREV = 0
      MPLOTOF = 0
      PI = 3.141592654
      TWOPI = 6.283185308                                          PSWAR-65
      G = 32.1725
      GXPI = G*PI
      TWOOVG = 2.0/G
      GOVTWO = 3/2.
      VSHIP = 0.
      IABOVEF=IBELOWF=0
      SPECMAXF=NUMSPEC=TSPECAVG=0.
```

```
      DO 50, N=1,2
      HHARF(N)=0.
      DO 50, I=1,4097
   50 FREQSPEC(I,N)=0.
C
C     READ IN DATA
C
  100 READ 9001,    NOS,IM(1),IM(2),DELT,V,CUT,H,NUMPT,LOWHI,NF,NAVGL,DF
      IF(EOF,60)    9999,200
  200 I1 = 0
      READ 9002,     LPH1
      READ 9003,    N1,N2,IPAUSE,PRINT,PHAS,PLTON,NRECSKP,NOWAVPLT,NPEN
     * ,NSPECAVG,IPLOTSP
      READ 9014,    NREC,          LI,LO,PLTSPACE,MTREW,UP,THETA,DFLASER
      READ 9020,   W,NLC,NAC,N3,NUMHIST,SWHONLY,WHDIST,IFILDAT
      READ 9023,   KFILE,(LFILE(I),I=1,7),ISWEEP,NFLAG
      READ 9015,    NGSPEC
      READ 9020, RESTART
      DFLASER= .DFLASER
      I1=NTOT=NOS
      XMAXVL = 0.6266
      REXTS = 0.
      RAVG = 0.0
C
C     PRINT OUT CONTROL CARDS
C
  215 PRINT 9029, NSETS,NREPEAT
      PRINT 9004,    NOS,IM(1),IM(2),DELT,V,CUT,H,NUMPT,LOWHI,NF,NAVGL,
     *DF,LPH1,N1,N2,IPAUSE,PRINT,PHAS,PLTON,NRECSKP,NOWAVPLT,NPEN,NSPECA
     *VG,IPLOTSP,NREC,   LI,LO,PLTSPACE,MTREW,UP,THETA,DFLASER
      PRINT 9021
      PRINT 9022,   W,NLC,NAC,N3,NUMHIST,SWHONLY,WHDIST,IFILDAT
      PRINT 9024
      PRINT 9023,   KFILE,(LFILE(I),I=1,7),ISWEEP,NFLAG
      PRINT 9015,    NGSPEC
      PRINT 9027, RESTART
      IF(IM(2) .NE. IM2PREV)    220,260
  220 IFS = -1
      IM2PREV = IM(2)
  260 IF(NPEN .EQ. 0)    270,275
  270 NPEN = 1
C
C     DOWNWIND TRACKS REQUIRE NEGATIVE (-) AIRCRAFT VELOCITIES
C     CONVERT AIRCRAFT VELOCITY FROM KNOTS TO FEET/SEC.
C     IF OMEGA = THETA, DOPPLER SHIFT SPECTRA AS IF WAVES MOVED PARALLEL
C     TO WIND.  IF OMEGA = 0 OR 180, IT IS ASSUMED THAT WAVES MOVED
C     PARALLEL TO FLIGHT TRACK.
  275 OMEGA = THETA
      IF(THETA.GT.90.AND.THETA.LT.270) 276,277
  276 OMEGA = 180.
      GO TO 278
  277 OMEGA = 0.
  278 V = V*1.6878*COSF(PI*OMEGA/180.)
      IF(THETA.EQ.90.OR.THETA.EQ.270) 280,290
  280 V=0.
C
C     SKIP NRECSKP FILES ON OUTPUT TAPE OR ON INPUT TAPE IF LI = LO.
  290 DO 350    I = 1,NRECSKP
      CALL SKIPFILE (LO)
  350 CONTINUE
```

```
      IF(VSHIP.EQ.0.) 523,520
C
C     CALCULATION WHICH ALLOWS SHIPBOARD RADAR AND AIRBORNE PROFILOMETER
C       TO ANALYZE DATA OVER TRACKS OF SIMILAR LENGTHS. IT DETERMINES
C       THE PROPER SAMPLE INTERVAL AND EVERY ISEC-TH POINT WILL BE USED.
C
  520 TOSHTR = 1024.*VSHIP*0.125
      VABS = ABSF(V)
      TIREAF = TOSHTR/VABS
      RIM1 = IM(1)
      TIREDA = TIREAF/RIM1
      RISEC = TIREDA/DELT + 0.99
      IF ( RISEC .LT. 1. ) 521,522
  521 RISEC = 1.
  522 ISEC = RISEC
      DELT = ISEC*DELT
      GO TO 524
C     IF A DESIRED SAMPLE INTERVAL IS LARGER THAN THAT OF THE ORIGINAL
C       DATA SET OR THAN THAT DETERMINED ABOVE, DEFINE THE DESIRED DELT
C       IN THE INPUT DECK AND THE BELOW EQUATION WILL PROPERLY DEFINE
C       ISEC PROVIDED THE DENOMINATOR IS CORRECT.
  523 ISEC = DELT/0.0111333
  524 PRINT 9019, ISEC
      PSEC = ISEC
      PLTSPACE = PSEC*PLTSPACE
      DX = ABSF(V*DELT)
      NUMPTP1 = NUMPT + 1
C
C     TEST IF FILTER IS TO BE COMPUTED,  IF(NUMPT .GT. 0) = YES
C
  525 IF(NUMPT.EQ.0) 1800,550
C
C     COMPUTE FILTER
C     NUMPT = NUMBER OF POINTS OVER WHICH THE AVERAGE IS TO BE TAKEN
C     CUT = CUT-OFF FREQUENCY/SAMPLING FREQUENCY
C     H     = SLOPE OF WEIGHTS
  550 KA = NUMPT + 1
      CTH = CUT * H
      FILT(KA) = 2.*CTH
      SUMK = 0.
      DO 700   I = 1,NUMPT
      P = I
      QQ = 1. - (16.*H*H*P*P)
      IF(QQ .NE. 0.)   600,575
  575 FILT(I) = 0.
      GO TO 700
  600 FILT(I) = (COSF(TWOPI*P*H)*SINF(TWOPI*P*CTH))/(PI*P*QQ)
      SUMK = SUMK + FILT(I)
  700 CONTINUE
      FLJO = (1. - (FILT(KA) + 2.*SUMK))/(2.*NUMPT + 1.)
      DO 800   I = 1,KA
      WEIGT(I) = FILT(I) + FLJO
  800 CONTINUE
      IF(LOWHI.EQ.2) 825,850
  825 WEIGT(KA)= 1. - WEIGT(KA)
      DO 840   I=1,NUMPT
  840 WEIGT(I)= -WEIGT(I)
C     CALCULATE AND PRINT FREQUENCY RESPONSE FUNCTIONS OF THE FILTER
  850 DO 900  MP=1,5
      BP2=FREFACTOR(MP)
```

```
      FR=1./(IM(1)*BP2)
      FORESF(MP)=WEIGT(KA)
      DO 900  IKJ=1,NUMPT
  900 FORESF(MP)=FORESF(MP) + 2.*WEIGT(IKJ)*COSF(TWOPI*IKJ*FR)
      PRINT 1927
      PRINT 1923,(FORESF(MP), MP=1,5)
 1800 CONTINUE
C
C     READ IN DATA
C
      IF(LI .EQ. LO)   1810,1840
C     IF READING IN MORE THAN ONE FILE PER RUN, NO NEED TO REWIND LI,
C     MERELY ADJUST NRECSKP ACCORDINGLY IN DATA DECK OF FOLLOWING FILE.
 1810 BUFFER IN(LI,1)(Y(1),Z(8192))
 1815 IF(UNIT,LI)   1815,1820,1820,1820
 1820 CALL SKIPFILE(LI)
      GO TO 2190
C
C     UNPACK AND ASSIGN VALUES TO Y AND Z
C
C     FOR UNPACKING FILES IN SEQUENCE OFF A TAPE, DO NOT REWIND LI,
C     MERELY SET KFILE=1+NUMBER OF LAST FILE UNPACKED IN DATA DECK OF
C     NEXT FILE, BUT,IF LI IS REWOUND, KFILE MUST = 1 INSTEAD.
 1840 I1 = 0
      NP=1
      DO 2155  IFILE = 1,NF
      DO 1870  JZ=NP,7
      IF(LFILE(JZ).EQ.0) 1870,1860
 1860 MFILE=JZ
      NP=JZ+1
      GO TO 1880
 1870 CONTINUE
 1880 CALL RDTAPE
      DO 2150 IREC= 1,NREC
      DO 2150  ISWP = 1,ISWEEP
      CALL UNPCK(ISWP,IREC,NFLAG)
       I1 = I1 + 1
       Y(I1) = CHAN(NLC)*DFLASER
      Z(I1) = CHAN(NAC)*DF
 2150 CONTINUE
      CALL SKIPFILE(LI)
 2155 CONTINUE
C     OPTION TO PHASE SHIFT DATA
      IF(PHAS.EQ.0) 2165,2160
 2160 CALL PHASE(NTOT,QP)
C     OPTION TO RECORD DATA BEFORE OR AFTER FILTER
 2165 IF(IFILDAT.EQ.1.AND.NUMPT.NE.0) 2190,2170
 2170 BUFFER OUT (LO,1) (Y(1),Z(8192))
 2175 IF(UNIT,LO) 2175,2180
 2180 ENDFILE LO
      IF(IFILDAT.EQ.1.AND.NUMPT.NE.0) 2185,2190
 2185 PRINT 9025
      GO TO 3440
 2190 IF(MTREW.ST.0) 2195,2200
 2195 REWIND LI
 2200 NTOT = NOS = I1
C
C PRINT FIRST VALUE OF EACH RECORD OF Y AND Z.
C
      PRINT 1925
```

```
      DO 2205, IZ = 1,NREG
      IR = (IZ - 1)*ISWEEP + 1
 2205 PRINT 1925, Y(IR),Z(IR)
C
C     CALCULATE YMAX,YMIN,ZMAX, AND ZMIN.
C
 2212 YMAX = ZMAX = -100.
      YMIN = ZMIN = 100.
      PRINT 9005,   NTOT
      DO 2300   I = 1,NTOT
      IF(Y(I) .GT. YMAX)   2220,2230
 2220 YMAX = Y(I)
      GO TO 2250
 2230 IF(Y(I) .LT. YMIN)   2240,2250
 2240 YMIN = Y(I)
 2250 IF(Z(I) .GT. ZMAX)   2260,2270
 2260 ZMAX = Z(I)
      GO TO 2300
 2270 IF(Z(I) .LT. ZMIN)   2280,2300
 2280 ZMIN = Z(I)
 2300 CONTINUE
      PRINT 9007,   YMAX,YMIN
      PRINT 9007,   ZMAX,ZMIN
      PRINT 9015
      IF(REXTS.EQ.0.) 2375,3400
 2375 IF(ISEC.GT.1) 2380,3440
C
C     SELECT LASER AND ACCELEROMETER DATA
C
 2380 I1=1
      DO 2600 I = 1 ,NTOT ,ISEC
      Y(I1) = Y(I)
      Z(I1) = Z(I)
 2600 I1 = I1 +1
      JISEC = I1 + 1
      IF(ISEC.EQ.1) 2660,2610
 2610 DO 2650 I = JISEC,NTOT
      Y(I) = 0.
 2650 Z(I) = 0.
 2660 NTOT=NOS=I1
C     FIND AVERAGE VALUES BEFORE FILTERING
      GO TO 3440
C
C     APPLY FILTER TO DATA (0 = NO)
C
 2700 RAVG = 1.0
 2800 NTOT = NTOT - 2*NUMPT
      MIN = 1
      DO 3200   I = MIN,NTOT
      KB = I + NUMPT
      SUMCK = WEIGT(KA)*Y(KB)
      SUMDK = WEIGT(KA)*Z(KB)
      DO 2900   J = 1,NUMPT
      IA = NUMPT + 1 - J
      IB = IA + NUMPT + I
      IC = J - 1 + I
      SUMCK = SUMCK + WEIGT(IA)*(Y(IC) + Y(IB))
      SUMDK = SUMDK + WEIGT(IA)*(Z(IC) + Z(IB))
 2900 CONTINUE
 3100 Y(I) = SUMCK
```

```
      Z(I) = SUMRK
 3200 CONTINUE
C     SET RESIDUAL DATA PTS TO 0.
      NTOTP1=NTOT + 1
      DO 3250 I=NTOTP1,NOS
 3250 Z(I)=Y(I)=0.
C     RECOMPUTE EXTREMES OF Y AND Z AFTER FILTERING
      REXIS = 1.
      GO TO 2212
 3400 IF(IFILDAT.EQ.1) 2170,3440
C
C     FIND AVERAGE VALUE OF INPUT
C
 3440 AVGY = AVGZ = 0.
      IF(NAVGL .GT. NTOT)   3450,3475
 3450 NAVGL = NTOT
 3475 DO 3500    I = 1,NAVGL
      AVGY = AVGY + Y(I)
      AVGZ = AVGZ + Z(I)
 3500 CONTINUE
      AVGY = AVGY/NAVGL
      AVGZ = AVGZ/NAVGL
      PRINT 1929, AVGY,AVGZ
      IF(NAVG.EQ.0.) 3550,3575
 3550 IF(NUMPT.EQ.0) 3575,2700
 3575 DO 3600    I = 1,NTOT
      Z(I) = Z(I) - AVGZ
 3600 Y(I) = Y(I) - AVGY
      YMAX=LABOVE(1)=YMAX - AVGY
      YMIN=LBELOW(1)=YMIN - AVGY
      ZMAX=LABOVE(2)=ZMAX - AVGZ
      ZMIN=LBELOW(2)=ZMIN - AVGZ
      NSPECTRA = NTOT/IM(1)
C
C     IF (PLTON .GT. 0)  DO NOT COMPUTE SPECTRA
C
      IF(PLTON.GT.0) 3625,3650
 3625 JTOT=NTOT
      NSTHIST=NT=NTIMES=1
      NSPECAVG = 1
      GO TO 4325
 3650 I1 = 1
      I2 = IM(1)
      I4 = I2/2 + 1
      I6 = I4 - 1
      FREQRES = 1./(2.*DELT*IM(1))
      FACT = DELT*IM(1)/TWOPI
      NTIMES=NSPECTRA/NSPECAVG
C     FOR THE GULF STREAM EXPERIMENT, SET NTIMES = 1.
      NTIMES = 1
      IF(NTIMES .LT. 1)   3660,3675
 3660 NTIMES = 1
C     IF NT=NTIMES CORRESPONDS TO DATA WHICH SHOULD NOT BE ANALYZED AND
C       IF N1=1, SET NT=NTIMES - 1.
 3675 DO 6450    NT = 1,NTIMES
      DO 4150 N = 1,2
      SPECTAVG = 0.
      IADD = 0
      NTOT = 0
      DO 3700, I=1,5500
```

```
 3700 U(I,N) = 0.
      NSTHIST = (NT-1)*NSPECAVG*IM(1) + 1
      JTOT = NSTHIST
      NSTH = 0
      DO 4100   I = 1,NSPECAVG
C     TEST FOR GOOD DATA. NSTHIST=START OF DESIRABLE DATA AND LOCATION
C       WHERE HISTOGRAM BEGINS.  FOLLOWING DO LOOP ALLOWS US TO KICK OUT
C       SEGMENTS OF LENGTH = IM(1) FROM THE ANALYSIS.
      DO 3730 J = 1,15
      IF((NT-1)*NSPECAVG + I.EQ.NGSPEC(J)) 3705,3730
 3705 NSTH =NSTH + 1
      IF(NSTH.EQ.1) 3710,3715
 3710 NSTHIST = I*IM(1) + NSTHIST
 3715 GO TO 4100
 3730 CONTINUE
      NTOT = NTOT + IM(1)
      L = 1
      IA = ((NT-1)*NSPECAVG + I - 1)*IM(1) + 1
      IB = ((NT-1)*NSPECAVG + I)*IM(1)
      IF((IB-IA).EQ.NAVGL) 3758,3751
C     FIND AVERAGE OF THE DATA SEGMENT (IA,IB)
 3751 YS = ZS = 0.
      IF(N.EQ.1) 3752,3754
 3752 DO 3753 JN=IA,IB
 3753 YS=YS + Y(JN + IADD)
      YS = YS/I2
      GO TO 3756
 3754 DO 3755 JN=IA,IB
 3755 ZS=ZS + Z(JN + IADD)
      ZS = ZS/I2
 3756 PRINT 1933, YS,ZS
 3758 DO 3800   J = IA,IB
      IF ( N  .EQ.  1 )  3760,3770
 3760 Q(L) = Y(J+IADD) - YS
      GO TO 3800
 3770 Q(L) = Z(J+IADD) - ZS
 3800 L = L + 1
      CALL FOURIER (Q,S,IM(2),IFS)
 3870 ROS =  2
C     CALCULATE POWER SPECTRA
 3895 DO 3900   J = 1,I4
 3900 Q(J) = Q(2*J-1)**2 + Q(2*J)**2
      DO 4000 J=1,I4
 4000 U(J,N)=U(J,N) + Q(J)
      SPECTAVG = SPECTAVG + 2.0
      IF(N.EQ.1) 4060,4070
 4060 PRINT 1934, Q(1)
      GO TO 4100
 4070 PRINT 1935, Q(1)
 4100 CONTINUE
      SPECAVGN(N) = SPECTAVG
 4150 CONTINUE
      TSPECAVG = TSPECAVG + SPECAVGN(1)/2.
C
C     TEST FOR END OF GOOD DATA SO AS TO AVOID PLOTTING UNDESIRED DATA
C      AT THE END OF DATA RECORD BEING ANALYZED IN ABOVE LOOPS.
C
      NFIN = NT*NSPECAVG
      JSTOP = 0
      IF(NGSPEC(NFIN).EQ.0) 4154,4151
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 4151 NSTA = (NT-1)*NSPECAVG + 1
      JSTOP = 1
      DO 4153 IMP = NSTA,NFIN
      JJP = NFIN - IMP + NSTA
      JJPM1 = JJP - 1
      IF(NGSPEC(JJP).EQ.NGSPEC(JJPM1) + 1) 4152,4154
 4152 JSTOP = JSTOP + 1
 4153 CONTINUE
 4154 JTOT= JTOT - NSTHIST + (NSPECAVG-JSTOP)*IM(1)
      PRINT 1930, SPECAVGN(1),SPECAVGN(2)
      IF(SPECTAVG.EQ.0.) 6400,4155
C
C     APPLY HAMMING TO THE TOTAL VARIANCE
C
 4155 DO 4170 N=1,2
      U(1,N)= 0.54*U(1,N) + 0.46*U(2,N)
      DO 4160 I=2,16
 4160 U(I,N)= 0.23*(U(I-1 ,N) + U(I+1,N)) + 0.54*U(I,N)
 4170 U(I4,N)= 0.54*U(I4,N) + 0.46*U(16,N)
C
C  DO LOOP TO TRANSFORM ACCELERATION TO DISPLACEMENT SPECTRUM
C  TRANSFORMATION SHOULD ONLY BE INITIATED FOR ACCELERATION DATA
C
 4171 U(1,1)=U(1,2)=0.
      DO 4175 LW=2,I4
      R=2*(LW-1)
      FTRU=R*FREQRES
      FTRU4 = (FTRU*TWOPI)**4
 4175 U(LW,2)=U(LW,2)/FTRU4
C
C     AVERAGE THE VARIANCES AND CALCULATE SIGNIFICANT WAVE HEIGHT
C
      EMAX(1) = EMAX(2) = 0.
 4180 DO 4200   I = 1,I4
      U(I,2) = J(I,2)/SPECAVGN(2)
      U(I,1) = J(I,1)/SPECAVGN(1)
C     N3=1, SUBTRACT A/C MOTION SPECTRUM FROM LASER SPECTRUM,
      IF(N3.EQ.1) 4182,4190
C     TEST VALUES OF THE VARIANCES--DO NOT ALLOW NEGATIVE VALUES OF U(1)
 4182 IF(U(I,1),LT.U(I,2)) 4184,4185
 4184 PRINT 1935, I,U(I,1),U(I,2)
      U(I,1)=0.0
      GO TO 4190
 4185 U(I,1) = J(I,1) - U(I,2)
 4190 EMAX(1) = EMAX(1) + U(I,1)
      EMAX(2) = EMAX(2) + U(I,2)
 4200 CONTINUE
 4203 HBAR(1) = 4.0*SQRTF(EMAX(1))
      HBAR(2) = SQRTF(EMAX(2))
C
C     WRITE HEADINGS
 4210 PRINT 9008, LPH1,NTOT,DFLASER,IM(1),CUT,DELT,H,V,NJMPT,EMAX(1),
     * HBAR(1),EMAX(2),HBAR(2),IFILT(LOWHI)
 4215 HBARF(1)=HBARF(1) + HBAR(1)
      HBARF(2) = HBARF(2) + HBAR(2)
      TNUMSPEC = TNUMSPEC + 1.0
      IF(N1.EQ.1.AND.NT.EQ.NTIMES) 4216,4217
 4216 HBARF(1)=HBARF(1)/TNUMSPEC
      HBARF(2)=HBARF(2)/TNUMSPEC
 4217 IF(SWHONLY.EQ.1.0) 4325,4219
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C
C  DO LOOP FOR CALCULATION OF POWER SPECTRA AND RELATED QUANTITIES
C    A DOPPLER SHIFT ALGORITHM IS INCLUDED TO REMOVE THE FREQUENCY SHIFT
C    DUE TO THE HORIZONTAL AIRCRAFT MOTION.  IF N2 EQUALS 1, AN ADDITION
C    AL CORRECTION IS APPLIED TO ACCOUNT FOR ANGULAR SPREADING AS PRE-
C    DICTED BY PHILLIP,S RESONANCE THEORY AND  IS APPLICABLE FOR FLIGHTS
C    THAT PARALLEL THE WIND DIRECTION.
C
 4219 DO 4300  N = 1,2
      IF(N.EQ.2) 4280,4220
 4220 PRINT 9009
 4221 MSAT = 1
C WANT TO PRINT EVERY NZ-TH PT PLUS FIRST 50 PT.
      NZ = I4/64
      ANZ = NZ
      DO 4265  I = 1,I4
      R = 2*(I-1)
      FTRU = R*FREQRES
      IF(V.EQ.0.) 4222,4223
 4222 FMUHT=2.*PI*FTRU
      GO TO 4225
 4223 CONST = G/(2.*V)
      CONSQ = CONST*CONST
      FMUHT = SQRTF(CONSQ + GXPI*R/(IM(1)*DX)) - CONST
 4224 IF(I.EQ.1. AND. CONST. GT. 0.)  4225,4226
 4225 FMUHT = 0.
 4226 ASQ1 = U(I,N)*DELT*IM(1)
      IF(V.EQ.0.) 4228,4230
 4228 ASQMU1 = ASQ1/TWOPI
      GO TO 4231
 4230 ASQMU1 = ARSF(TWODVG*(FMUHT + CONST)*ASQ1*V)/TWOPI
 4231 ASQKT1 = 0.
      IF(N2.EQ.1) 4232,4242
C     STATEMENTS 4232 TO 4242 PERFORM THE RESONANCE THEORY DOPPLER SHIFT
 4232 IF(FMUHT.EQ.0.) 4234,4236
 4234 FKT = ASQMU1 = ASQ2NU(I,N) = FNUHT(I,N) = 0.
      GO TO 4245
 4236 FMUHT = W*FMUHT**2/G
 4240 ASQMU1 = ASQMU1*SQRT(G/(FMUHT*W))/2.
 4242 FNUHT(I,N) = FMUHT/TWOPI
      FKT = (FMUHT**2)/G
      ASQ2NU(I,N) = TWOPI*ASQMU1
      FREQSPEC(I,N) = FREQSPEC(I,N) + ASQ2NU(I,N)
      IF(FMUHT.NE.0.)  4244,4246
 4244 ASQKT1 = ASQMU1*GDVTWO/FMUHT
 4246 IF(PRINT.EQ.0.) 4247,4265
 4247 IF(I4.GT.128) 4248,4249
 4248 PRNUM1 = I
      PRNUM2 = PRNUM1/ANZ
      IPR1 = PRNUM2
      PRNUM3 = IPR1
      PRNUM4 = PRNUM2 - PRNUM3
      IF(I.LE.50.OR.PRNUM4.EQ.0.) 4249,4265
 4249 IF(I.LE.NJMPT + 1)  4250,4255
 4250 PRINT 9019,FTRU,U(I,N),ASQ1,FMUHT,ASQMU1,FNUHT(I,N),ASQ2NU(I,N),
     *FKT,ASQKT1,WEIGT(I)
      GO TO 4265
 4255 PRINT 9019,FTRU,U(I,N),ASQ1,FMUHT,ASQMU1,FNUHT(I,N),ASQ2NU(I,N),
     *FKT,ASQKT1
 4265 CONTINUE
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```
      GO TO 4300
 4280 PRINT 9011
      DO 4290 I = 1,I4
      R = 2*(I-1)
      FTRU = R*FREQRES
      FMUHT(I,N) = FTRU
      FMUHT = FTRU*TWOPI
      ASQ2 = U(I,N)*DELT*IM(1)
      ASQ2NU2 = ASQ2
      ASQMU2 = ASQ2/TWOPI
      IF(PRINT.EQ.0.) 4285,4289
 4285 IF(I4.GT.128) 4286,4288
 4286 PRNUM1 = I
      PRNUM2 = PRNUM1/ANZ
      IPR1 = PRNUM2
      PRNUM3 = IPR1
      PRNUM4 = PRNUM2 - PRNUM3
      IF((I.LE.5).OR.PRNUM4.EQ.0.) 4288,4289
 4288 PRINT 9011, FTRU,U(I,N),ASQ2,FMUHT,ASQMU2
 4289 ASQ2NU(I,N) = ASQ2NU2
      FREQSPEC(I,N) = FREQSPEC(I,N) + ASQ2NU(I,N)
 4290 CONTINUE
 4300 CONTINUE
C
C     CALCULATE WAVE HEIGHT DISTRIBUTION FUNCTION
C     IF SPECTRA (IPLOTSP NE 0) ARE NOT PLOTTED, THEN PLOT FOR
C     THE WAVE HEIGHT DISTRIBUTION MAY BE POSITIONED WRONG.  ALSO,
C     THERE IS NO EQUIVALENT TO FREQSPEC FOR THIS PARAMETER.
C
 4325 DO 6000   N = 1,2
      IADD = 0
 4375 DO 4400   M = 1,301
 4400 DFNC(M,N) = 0.
      DO 4500    M = 1,NSPECAVG
      MA = ((NT-1)*NSPECAVG + M - 1)*IM(1) + 1
      MB = ((NT-1)*NSPECAVG + M)*IM(1)
      DO 4415   MM = 1,25
      IF((NT-1)*NSPECAVG + M .EQ. NGSPEC(MM))   4500,4415
 4415 CONTINUE
      DO 4500   MM = MA,MB
      IF ( N  .EQ.  1 )  4416,4417
 4416 INDEX = Y(MM+IADD)*4.0 + 151.5
      GO TO 4418
 4417 INDEX = Z(MM+IADD)*4.0 + 151.5
 4418 IF(INDEX .LT. 1)   4425,4450
 4425 INDEX = 1
      GO TO 4485
 4450 IF(INDEX .GT. 301)   4475,4485
 4475 INDEX = 301
 4485 DFNC(INDEX,N) = DFNC(INDEX,N) + 1
 4500 CONTINUE
      DO 4600   M = 5,301
      IF(DFNC(M,N) .GT. 0.)   4700,4600
 4600 CONTINUE
 4700 IST(N) = 4-XMODF(M,4)  + 1
      IF(IST(N) .LT. 1)   4725,4750
 4725 IST(N) = 1
 4750 DO 4800   MM = 4,301
      M = 301 - MM
      IF(DFNC(M,N) .GT. 0)   4900,4800
```

```
 4800 CONTINUE
 4900 IND(N) = M +  1-XMOUF(M,4)
      IF(IND(N) .GT. 301)   4925,4950
 4925 IND(N) = 301
 4950 CENTROID = STANDDEV = SKEWNESS = KURTOSIS = 0.
      DEV = (IST(N) - 151)/4.
      I = IST(N)
      J = IND(N)
      FNTOT = NTOT
      DO 5000   M = I,J
      CENTROID=CENTROID+DFNC(M,N)*DEV
      STANDDEV = STANDDEV + DFNC(M,N)*DEV**2
      SKEWNESS = SKEWNESS + DFNC(M,N)*DEV**3
      KURTOSIS = KURTOSIS + DFNC(M,N)*DEV**4
 5000 DEV = DEV + 0.25
      CENTROID = CENTROID/FNTOT
      STANDDEV = STANDDEV/FNTOT
      SKEWNESS = SKEWNESS/FNTOT
      KURTOSIS = KURTOSIS/FNTOT
      KURTOSIS = KURTOSIS - 4.*CENTROID*SKEWNESS + 6.*CENTROID*CENTROID*
     * STANDDEV - 3.*CENTROID**4
      SKEWNESS = SKEWNESS - 3.*CENTROID*STANDDEV + 2.*CENTROID**3
      VARIANCE = STANDDEV - CENTROID*CENTROID
      STANDDEV = SQRTF(VARIANCE)
      SKEWNESS = SKEWNESS/(STANDDEV*VARIANCE)
      KURTOSIS = KURTOSIS/(VARIANCE*VARIANCE)
      PRINT 9012,   N,I,N,J,CENTROID,STANDDEV,SKEWNESS,KURTOSIS
 6000 CONTINUE
      MIN = XMINOF(IST(1),IST(2))
      MAX = XMAXOF(IND(1),IND(2))
      IBELOW = (154 - MIN)/4
      IABOVE = (MAX - 148)/4
      IBELOW = IBELOW - 4*MOD(IBELOW,2)
      IABOVE = IABOVE + 4*MOD(IABOVE,2)
      MIN = 151 - 4*IBELOW
      MAX = 151 + 4*IABOVE
      IF(MIN .LE. 3  .AND.  MAX .GE. 299)   6025,6030
 6025 IBELOW = IABOVE = 50
 6030 IF(HBAR(1).LT.0.) 6070,6050
 6050 IF(IBELOWF.LT.IBELOW) 6055,6060
 6055 IBELOWF = IBELOW
 6060 IF(IABOVEF.LT.IABOVE) 6065,6070
 6065 IABOVEF = IABOVE
C
C     PLOT DESIRED RESULTS.
C
 6070 IF(NOWAVP.EQ.1) 6150,6100
 6100 CALL PLOT2(JTOT,NUMPT,IM(1),IPLOTSP,LBELOW,LABOVE,NUMHIST,N1,
     2 NSTHIST,NT,NTIMES,NOS,SWHONLY)
 6150 IF(PLTON.NE.0.OR.SWHONLY.EQ.1.0) 6500,6160
 6160 FSPECMAX = FDMAX = 0.
      DO 6400   N = 1,2
 6164 DO 6200 I=1,I4
      IF(N1.EQ.1.AND.NT.EQ.NTIMES)  6165,6170
 6165 FREQSPEC(I,N)=FREQSPEC(I,N)/TNUMSPEC
 6170 IF(ASQ2NU(I,N).GT.FSPECMAX) 6175,6200
 6175 FSPECMAX = ASQ2NU(I,N)
 6200 CONTINUE
      IF(SPECMAXF.LT.FSPECMAX) 6215,6225
 6215 SPECMAXF=FSPECMAX
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 6225 DO 6300, I=MIN,MAX
      IF(DFNC(I,N) .GT. FDMAX)   6250,6300
 6250 FDMAX = DFNC(I,N)
 6300 CONTINUE
 6400 CONTINUE
      IF(N1.EQ.1.AND.NT.EQ.NTIMES) 6403,6406
C     ASSIGN VALUES TO FNUHTF
 6403 DO 6405 NB=1,2
      DO 6405 ID=1,4097
 6405 FNUHTF(ID,NB)= FNUHT(ID,NB)
 6406 IF(HBAR(1).LT.0.) 6409,6407
 6407 IF(IPLOTSP.EQ.0) 6408,6409
 6408 CALL PLTSPEC (ASQ2NU,FNUHT,LPH1,HBAR,I4,1,FSPECMAX,NOWAVPLT,
     *XMAXVL,ISEC,IBELOW,IABOVE,MSAT,N2,THETA,N1,NOS,PLTSPACE)
 6409 IF(N1.EQ.1.AND.NT.EQ.NTIMES)  6410,6415
 6410 PRINT 9025, HBARF(1),HBARF(2),TSPECAVG
      PRINT 9030
      DO 6412  KM=1,75
 6412 PRINT 9031,  FNUHTF(KM,2),FREQSPEC(KM,2),FNUHTF(KM,1),
     2  FREQSPEC(KM,1)
      CALL PLTSPEC(FREQSPEC,FNUHTF,LPH1,HBARF,I4,1,SPECMAXF,NOWAVPLT,
     2XMAXVL,ISEC,IBELOWF,IABOVEF,MSAT,N2,THETA,N1,NOS,PLTSPACE)
 6415 IF(ISEC.EQ.1.AND.WHOIST.EQ.0.0) 6425,6450
 6425 CALL PLOTDF (FDMAX,IBELOW,IABOVE,MIN,MAX,LPH1,MPLOTDF)
 6450 CONTINUE
 6500 IF(IPAUSE .NE. 0)   6600,6720
 6600 PAUSE
 6720 IF(RESTART.EQ.1.) 6900,100
 6900 CONTINUE
 9999 CALL STOPPLOT
      END
      SUBROUTINE PLOT2 (NPS,NUMPT,IM,PLTONLY,LBELOW,LABOVE,NUMHIST,N1,
     2 NST,NT,NTIMES,NSAMP,SWHONLY)
      DIMENSION LBELOW(2),LABOVE(2)
      COMMON/SF/NPEN,PLTSPACE,DELT
      COMMON/A/Y(8192),Z(8192)
      TYPE REAL  LABOVE,LBELOW
      TYPE INTEGER   PLTONLY,IDEC
C     NOTE THAT DELT AND PLTSPACE HAVE SWITCHED LOCATIONS AND VALUES.
  210 FORMAT(/,3X,*NSAMP = *,I5)
      PRINT 210, NSAMP
C       FOR GULFSTREAM EXPERIMENT, NUMPT = 512.
      NUMPT = 512
      NFINAL = NST + NPS - 1
      XXFMAX = NSAMP*DELT
      NPTS = IM
      CALL NEWPEN(NPEN)
      IF(NSAMP - 2*NUMPT,EQ.NPS) 3,1
C     RECALCULATE LABOVE,LBELOW
    1 LBELOW(1)= LBELOW(2)=0.
      LABOVE(1)=LABOVE(2)=0.
      DO 200 I=NST,NFINAL
      IF(LABOVE(1).LT.Y(I)) 180,184
  180 LABOVE(1)=Y(I)
      GO TO 188
  184 IF(LBELOW(1).GT.Y(I)) 186,188
  186 LBELOW(1)=Y(I)
  188 IF(LABOVE(2).LT.Z(I)) 190,192
  190 LABOVE(2)=Z(I)
      GO TO 200
```

```
  192 IF(LBELOW(2).GT.Z(I))194,200
  194 LBELOW(2)=Z(I)
  200 CONTINUE
    3 IF(PLTONLY.GT.0.OR.SWHONLY.EQ.1.0)  8,4
    4 CALL PLOT(0.0, 15.0,-3)
    8 CALL SYMBOL (-1.0,1.70,0.35,19HMEASUREMENTS IN MKS, 90,0,20)
      CALL PLOT(0.0,5.0,-3)
C
C     SET UP VERTICAL AXIS OF LASER PLOT
C
      IMARK = 4
      XM = IMAR(/2.
      RABOVE = _ABOVE(1)
      ABOVE = RABOVE*0.3048
      RBELOW = _BELOW(1)
      BELOW = RBELOW*0.3048
      ABBELOW = ABSF(BELOW)
      SCALAR = MAX1F(ABOVE,ABBELOW)
      XMID = 2.0
      CALL PLOT(-0.1,0.0,3)
      CALL PLOT(0.0,0.0,2)
      DO 10  I = 1,4
      YY = I
      CALL PLOT ( 0.0,YY,1)
      CALL PLOT (-0.1,YY,1)
      CALL PLOT ( 0.0,YY,1)
   10 CONTINUE
      CALL NUMBER (-0.6, 3.95, 0.105, SCALAR,0.0,4HF6.2)
      SCALAR = -SCALAR
      CALL SYMBOL (-0.6, 1.95, 0.105, 4H   0,0.0,4)
      CALL SYMBOL (-0.6, 1.58, 0.210,5HLASER,90,0,5)
      CALL NUMBER (-0.6,-0.05, 0.105, SCALAR,0.0,4HF6.2)
      SCALAR = -SCALAR/2.
C
C     PLOT LASER RECORD
C
      XX = DELT*(NUMPT + NST)
      LL = 3
      DO 20 I = NST,NFINAL
      YAMP = Y(I)*0.3048/SCALAR+XMID
      IF(YAMP .GT. 4.0)   12,14
   12 YAMP = 4.0
      GO TO 17
   14 IF(YAMP .LT.  0.0)   16,17
   16 YAMP =  0.
   17 CALL PLOT (XX,YAMP,LL)
      IF(LL - 2)   175,170,170
  170 LL = LL - 1
  175 IF(PLTONLY .EQ. 0)   20,18
   18 IF(MOD(I,NPTS)  .EQ. 0)   19,20
   19 CALL PLOT (XX,4.5,3)
      CALL PLOT (XX,4.0,2)
      CALL PLOT (XX,YAMP,3)
      CALL PLOT (XX,YAMP,2)
   20 XX = XX + DELT
C
C     SET UP HORIZONTAL AXIS
C     IMARK SHOULD BE AN EVEN INTEGER
C
      DELTAX = XXFMAX/IMARK
```

```
      CALL PLOT (XXFMAX,-0.5,3)
      JMARK = IMARK + 1
      DO 30 I=1,JMARK
      XA = XXFMAX - (I-1)*DELTAX
      XB = XA+P_TSPACE/DELT
      CALL PLOT (XA,-0.5,2)
      CALL PLOT (XA,-0.55,1)
      CALL PLOT (XA,-0.45,1)
      CALL NUMBER (XA-0.255,-0.40,0.105,XB,0.0,4HF4.0)
      IF(I.EQ.IMARK/2 + 1) 25,27
   25  CALL SYMBOL (XA - 0.88,-0.85,0.14,15HTIME IN SECONDS,0.0,15)
   27 CALL PLOT (XA,-0.5,3)
   30 CONTINUE
      IF(NJMHIST.EQ.2) 32,55
C
C     SET UP VERTICAL AXIS OF ACCELERATION PLOT
C
   32 CALL PLOT (0.,-5.0,-3)
      CALL PLOT (-0.1,0.0,3)
      CALL PLOT ( 0.0,0.0,2)
      DO 40     I = 1,4
      YY = I
      CALL PLOT ( 0.0,YY,1)
      CALL PLOT (-0.1,YY,1)
      CALL PLOT ( 0.0,YY,1)
   40 CONTINUE
      RABOVE = _ABOVE(2)
      ABOVE = RABOVE*0.3048
      RBELOW = _BELOW(2)
      BELOW = RBELOW*0.3048
      ABBELOW = ABSF(BELOW)
      SCALAR = MAX1F(ABOVE,ABBELOW)
      CALL NUMBER (-0.6, 3.95, 0.105, SCALAR,0.0,4HF6.2)
      SCALAR = -SCALAR
      CALL SYMBOL (-0.6, 1.95, 0.105, 4H    0,0.0,4)
      CALL SYMBOL (-0.6, 1.58, 0.210,5HACCEL,90.0,5)
      CALL NUMBER (-0.6,-0.05, 0.105, SCALAR,0.0,4HF6.2)
      SCALAR = -SCALAR/2.
      XX = DELT*(NUMPT + NST)
      LL = 3
C
C     PLOT ACCE_ERATION RECORD
C
      DO 50 I = NST,NFINAL
      YAMP = Z(I)*0.3048/SCALAR + XMID
      IF(YAMP .3T. 4.5)   42,44
   42 YAMP = 4.5
      GO TO 48
   44 IF(YAMP .LT. -0.5)   46,48
   46 YAMP = -0.5
   48 CALL PLOT (XX,YAMP,LL)
      IF(LL-2)   50,49,49
   49 LL = LL - 1
   50 XX = XX + DELT
      CALL PLOT(0.0,5.0,-3)
C
C     POSITION PEN FOR NEXT PLOT
C
   55 IF(SWHONLY.EQ.1.0) 56,58
   56 CALL PLOT(0.0,4.5,-3)
```

```
      GO TO 66
   58 IF(PLTONLY.EQ.0) 60,62
   60 CALL PLOT(0.0,-19.0,-3)
      GO TO 66
   62 IF(N1.EQ.1.AND.NT.EQ.NTIMES) 64,56
   64 XF=XXFMAX + 4.0
      CALL PLOT(XF,-8.0,-3)
   66 RETURN
      END
      SUBROUTINE  PLTSPEC (YP,XP,LPH1,HBAR,NOP,NP,YMAX,NOWAVPLT,
     *XMAXVL,ISEC,IBELOW,IABOVE,MSAT,N2,THETA,N1,NCS,PLTSPACE)
      DIMENSION  YP(4097,2),XP(4097,2),LPH1(10)
      DIMENSION HBAR(2),ISTART(2)
      TYPE INTEGER  THETA
C
C     LPH1 CONTAINS PLOTTING LABEL TO BE PLOTTED ON TOP OF PLOT
C     MAXIMUM OF 72 CHARACTERS PLOTTED OUT
C
C     YP(I,N) = ARRAY OF Y VALUES OF THE N-TH VARIABLE TO BE PLOTTED
C     XP(I,N) = ARRAY OF X VALUES OF THE N-TH VARIABLE TO BE PLOTTED
C     NOP     = TOTAL NUMBER OF POINTS
C     NP      = STARTING POINT IN ARRAY FROM WHICH TO START PLOTTING
C     FMAX = PHYSICAL LENGTH OF ABSISSA
C     XLEFT = LOG OF MINIMUM VALUE ON ABSISSA
C     XMAXVL = LOG OF MAXIMUM VALUE ON ABSISSA
  200 FORMAT(/,2X,*ISTART(1) =*,I3,5X,*NOPP =*,I5,5X,*ISTART(2) =*,I3,
     2 5X,*NOP =*,I5,/)
  390 FORMAT(3X,*LASTPLT= *,I5)
C
      CONVTM = 0.3048
      CONVETM = CONVTM**2
      CONV = 1./LOGF(10.)
      ATHETA = THETA
      IF(THETA.ST.180) 525,550
  525 THETA = 360 - THETA
  550 DO 3, N=1,2
    2 ISTART(N) = 1
    3 CONTINUE
      CALL NEWPEN(1)
    6 FMAX = 12
C
C     CONVERT DATA TO METRIC SYSTEM
C
      HBAR(1) = CONVTM*HBAR(1)
      HBAR(2) = CONVTM*HBAR(2)
      DO 10 I = 1,NOP
      YP(I,1) = CONVETM*YP(I,1)
   10 YP(I,2) = CONVETM*YP(I,2)
      YMAX = CONVETM*YMAX
C
C     DETERMINE INITIAL Y AND Z VALUES FOR PLOTS, CALCULATE LOG VALUES
C
      XMAXVL = 0.5
      XLEFT = -2.5
      XLEFT10 = 10.**XLEFT
      SCALE = 5.
      DO 103 N = 1,2
      DO 100 I=1,NOP
      IF(XP(I,N) .LT. XLEFT10) 50,60
   50 ISTART(N)= I+1
```

```
      GO TO 100
   60 XPL = XP(I,N)
      XPL = LOGF(XPL)
      XP(I,N)=CONV*XPL
  100 CONTINUE
  103 CONTINUE
      IF(N2.EQ.1) 104,106
  104 IF(MSAT.GT.ISTART(1)) 105,106
  105 ISTART(1) = MSAT
  106 ISTART1 = ISTART(1)
C
C     SET UP BOTH AXES, PLOT AND LABEL VERTICAL AXIS
C
      DO 108 I = ISTART1,NOP
      IF (XP(I,1) .GT. XMAXVL) 107,108
  107 NOPP = I-1
      GO TO 109
  108 CONTINUE
      NOPP = NOP
      XMAXLVL = XMAXVL-XLEFT
      XMIN = FMAX/XMAXLVL
      GO TO 110
  109 XMAXLVL = XP(NOPP,1) - XLEFT
      XMIN = FMAX/XMAXLVL
  110 YMAX = LOGF(YMAX)
      YMAX = CONV*YMAX
      YMAX = YMAX+1.
      JYMAX = YMAX
      YTOP = JYMAX
      YBOTTOM = YTOP-SCALE
      YBOTTOMR = 10.**YBOTTOM
      CALL PLOT ( 0.0, -0.1,3)
      CALL PLOT ( 0.0,  1.0,2)
      DO 111  I = 1,9
      Y = I
      CALL PLOT (-0.1, Y,1)
      CALL PLOT ( 0.0, Y,1)
      CALL PLOT ( 0.0,Y+1.,1)
  111 CONTINUE
      CALL PLOT (-0.1 , Y+1. , 1 )
      CALL SYMBOL (0.5,10.1,0.14,LPH1,0.0,72)
      CALL SYMBOL (9.08,9.57,0.14,0.0,-1)
      CALL SYMBOL (9.15,9.50,0.14,26H - LASER (SWH =        M, ),0.0,26)
      CALL NUMBER (11.07, 9.50,0.14,HBAR(1),0.0,4HF5.2)
      CALL SYMBOL (9.08,9.32,0.14,4,0.0,-1)
      CALL SYMBOL (9.15,9.25,0.14,30H - A/C DISP. (STD =        M, ),0.0,
     +30)
      CALL NUMBER (11.60, 9.25,0.14,HBAR(2),0.0,4HF5.2)
      CALL SYMBOL(9.15,9.00,0.14,8HTHETA = ,0.0,8)
      CALL NUMBER(10.15,9.00,0.14,ATHETA,0.0,4HF5.1)
      YY = 9.95
      FLABEL = YTOP
      DO 116 I = 1,6
      CALL NUMBER (-0.8,YY,0.105,FLABEL,0.0,4HF6.2)
      FLABEL = FLABEL - SCALE/5.
      YY = YY - 2.0
      IF(I .EQ. 4) 115,110
  115 CALL SYMBOL (-0.8,3.6,0.175,22HLOG(SPECTRA)  M**2-SEC,90,0.22)
  116 CONTINUE
C
```

```
C     TRANSFORM DEPENDENT VARIABLE TO LOG BASE 10, CONVERT COORDINATES
C      TO INCHES.
C
      JJ = NOPP
      DO 121 N = 1,2
      IF(N.EQ.2) 117,119
  117 JJ = NOP
  119 ISTART1 = ISTART(N)
      DO 120 I = ISTART1,JJ
      YPL = YP(I,N)
      IF(YPL.LE.YBOTTOMR) 1002,1000
 1000 YPL = LOGF(YPL)
      YP(I,N) = CONV*YPL - YBOTTOM
      YP(I,N) = YP(I,N)/SCALE*10.
      GO TO 1004
 1002 YP(I,N) = 0.
 1004 XP(I,N) = XP(I,N) - XLEFT
  120 XP(I,N) = XP(I,N)*XMIN
  121 CONTINUE
      FMID = FMAX/2.
      J1 = 0
      NEND = NOPP - NP + 1
      JJ = NEND
      IF(  THETA.LE.90.AND.ISTART(1).EQ.1) 122,210
  122 ISTART(1) = 2
  210 PRINT 200, ISTART(1),NOPP,ISTART(2),NOP
C
C     PLOT SPECTRA (LOG-LOG)
C
      INZ=NOP/256
      ANZ=INZ
      DO 140 N = 1,2
      L = -1
      IF(N.EQ.2)  123,125
  123 J1 = 4
      JJ = NOP
  125 ISTART1 = ISTART(N)
      DO 135 I = ISTART1  ,JJ
      NN = I
      IF(N.EQ.2) 127,129
  127 NN = JJ - I + ISTART(2)
  129 IF(YP(NN,N) .LE. 0.) 131,133
  131 L = 0
      GO TO 135
  133 IF(N.EQ.2) 134,500
C     LIMIT THE NUMBER OF HIGH FREQ PTS PLOTTED (LASER)
  500 PRNUM1=NN
      PRNUM2=PRNUM1/ANZ
      IPR1=PRNUM2
      PRNUM3=IPR1
      PRNUM4=PRNUM2-PRNUM3
      IF(NN.LE.125.OR.PRNUM4.EQ.0.) 134,135
  134 CALL SYMBOL (XP(NN,N),YP(NN,N),0.07,J1,0.0,L)
      LASTPLT = NN
  135 L = L - 1
  140 CONTINUE
C
C     PLOT AND LABEL HORIZONTAL AXIS, POSITION PEN FOR NEXT PLOT
C     IF XLEFT OR XMAXVL IS CHANGED, LIMITS FOR DO LOOPS MAY CHANGE
C
```

```
      XINC = FMAX*0.5/XMAXLVL
      CALL PLOT(-0.1, 0. , 3 )
      CALL PLOT (XINC,0.,2)
      X = 0.
      DO 141 I = 1,5
      X = X + XINC
      CALL PLOT ( X , -0.1 , 1 )
      CALL PLOT ( X , 0. , 1 )
      CALL PLOT (X + XINC, 0.,1)
  141 CONTINUE
      CALL PLOT (X + XINC, -0.1, 1)
      X =  -0.3
      XX = 0.
      DO 150 I = 1,7
      FREQ = XX/XMIN+XLEFT
      CALL NUMBER (X,-0.20,0.105,FREQ,0.0,4HF6.3)
      IF(XX .GT. FMID-1.5  .AND.  XX .LE. FMID)  145,149
  145 CALL SYMBOL (FMID-1.47,-0.5,0.175,20HLOG(FREQUENCY) HZ   ,0.0,20)
  149 XX = XX + XINC
  150 X = X + XINC
      IF(NOWAVP_T.EQ.1) 155,157
  155 CALL PLOT(FMAX + 4.,0.0,-3)
      GO TO 180
  157 IF ( ISEC  .EQ.  1 )  160,170
  160 IF(N1.EQ.1) 162,165
  162 CALL PLOT (FMAX + 5.0,0.0,-3)
      GO TO 180
  165 XFIN = NO3*PLTSPACE + 5.0
      CALL PLOT (XFIN,0.0,-3)
      GO TO 180
  170 NPOINTS = (IABOVE+IBELOW)*4
      INCHES = NPOINTS/4
      IISTAN = INCHES+9
      DISTAN = IISTAN
      CALL PLOT (FMAX+DISTAN,0.0,-3)
  180 RETURN
       END
      SUBROUTINE  PLOTDF(DM,IBELOW,IABOVE,MIN,MAX,LPH1,MPLOTDF)
      RETURN
      END
      SUBROUTINE RDTAPE
      COMMON/RDTAPEB/LFILE(7),KFILE,IFILE,MFILE
      IF(MFILE-KFILE.EQ.0) 30,10
   10 K1=MFILE-KFILE
      DO 20 I=1,K1
   20 CALL SKIPFILE(5)
      KFILE=MFILE + 1
   30 CALL UNPCK(0,0,0)
      RETURN
      END
      SUBROUTINE UNPCK(ISWP,IREC,NFLAG)
      DIMENSION INS1(8,8),INS(264),VSCOPE(9),INS2(8),NRA(11000),
     1NRAD(167)
      COMMON/UNPCKB/RAD(100),CHAN(7),AINSS(8),INCODE(8),NFILE,
     1NDAY,MONTH,NYR,NHR,MIN,ALT,DDOT,NHSCOPE,NVSCOPE,VSCALE,ISWEEP
      COMMON/B/J(5500,2),NUMTF(4097,2)
      EQUIVALENCE (NRA,U,NUMTF)
      DATA (M1=17B),(M2=7777B),(M3=1B),(M4=3700B),(M5=1000B)
      DATA (M6=777777777776000B),(MSK1=77774000006),
     C(MSK2=77777400008),(MSK3=377B),(MSK4=140000000008),
```

```
      C(MSK5=77777700000000008)
       DATA (MC=3/8),((VSCOPE(I),I=1,9)=1.,2.,5.,10.,20.,50.,100.,200.,
      C500.)
       IF(IREC.EQ.0)2000,1020
 2000 CONTINUE
       BUFFER IN(5,1)(NRA(1),NRA(2))
  110 IF(UNIT,5)110,30,30,40
   40 PRINT 50
   50 FORMAT( *  PARITY ERROR IN FIRST RECORD*)
   30 DO 1 J=1,2
       DO 1 I=1,3
       MTS=NRA(J)/2**((I-1)*6)
       INS1(I,J)=MTS.AND.M1
    1 CONTINUE
       NFILE=INS1(4,1) $NDAY=INS1(8,1)*10+INS1(7,1)
       MONTH=INS1(6,1)*10+INS1(5,1) $NYR=70+INS1(3,1)
       NHR=INS1(2,1)*10+INS1(1,1)
       MIN=INS1(8,2)*10+INS1(7,2)
       ALT=INS1(6,2)*10+INS1(5,2)
       DDOT=INS1(4,2)*10.+INS1(3,2)
       NHSCOPE=INS1(2,2)
       NVSCOPE=INS1(1,2)
       VSCALE=VSCOPE(NVSCOPE)
       PRINT 100,NFILE,NDAY,MONTH,NYR
  100 FORMAT(1X,5HFILE ,I2,2X,I2,1H/,I2,1H/,I2,//)
       PRINT 101,NHR,MIN
  101 FORMAT(1X,7HTIME=  ,I2,3HHR ,2X,I2,4HMIN ,I2,//)
       PRINT 102,DDOT,NVSCOPE,NHSCOPE,ALT
  102 FORMAT(2X,10HDELAY DOT=,F4.1,2X,11HVERT SCALE=,
      C1X,I2,2X,10HHOR SCALE=,1X,I2,2X,4HALT=,F5.1,//)
       IRC=0
       RETURN
 1020 CONTINUE                                  IF(IRC.EQ.IREC) 75,52
       IRC=IREC                            52 IRC2 = IREC - IRC
       DO 77 IBUF=1,IRC2
   55 BUFFER IN(5,1)(NRA(1),NRA(11000))
   60 IF(UNIT,5)60,70,65,80
   80 PRINT 90
   90 FORMAT( *  PARITY ERROR IN SWEEP DATA*)
       GO TO 70
   65 CONTINUE
   70 CONTINUE
   77 CONTINUE
   75 CONTINUE
       MM=(IREC-1)*ISWEEP+ISWP
       JJ=MOD(MM,256)
       DO 301 J=1,NFLAG
       NUM=(ISWP-1)*167+J
       IWORD=(NUM+3)/4
       NSHIFT=(4*IWORD-NUM)*12
       NRAD(J)=NRA(IWORD)/2**NSHIFT
       MTS=NRAD(J)
       NRAD(J)=MTS.AND.M2
  301 CONTINUE
       IF(JJ.EQ.1)302,109
  302 I=0
       DO 3 J=1,132
       I=I+1
       MTS=NRAD(J)/2**11
       INS(I)=MTS.AND.M3
```

```
      I=I+1
      MTS=NRAD(J)/2**5
      INS(I)=MTS.AND.M3
    3 CONTINUE
      I1=7
      DO 11 K=1,8
      INS2(K)=0
      DO 10 I=1,8
      I1=I1+1
      INS2(K)=INS(I1)*2**(8-I)+INS2(K)
   10 CONTINUE
      DO 210 I=9,32
      I1=I1+1
      INS2(K)=INS(I1)*2**(I-1)+INS2(K)
  210 CONTINUE
   11 CONTINUE
      DO 20 K=1,8
      INCODE(K)=MTS.AND.MSK3
      MTS=INS2(K)
      IF(K.EQ.2.OR.K.EQ.5)133,14
  133 INS2(K)=MTS.AND.MSK2
      GO TO 15
   14 INS2(K)=MTS.AND.MSK1
   15 NSIGN=MTS.AND.MSK4
      IF(NSIGN.NE.0)16,17
   16 MTS=INS2(K)-1
      INS2(K)=MTS.OR.MSK5
   17 CONTINUE
      IF(K.EQ.2.OR.K.EQ.5)18,19
   18 AINSS(K)=INS2(K)/2**29*3276.7
      GO TO 20
   19 AINSS(K)=INS2(K)/2**29*180.
   20 CONTINUE
      AINSS(5)=AINSS(5)*2.
      IF(AINSS(3).LT.0.)22,24
   22 AINSS(3)=AINSS(3)+360.
   24 IF(AINSS(4).LT.0.)26,28
   26 AINSS(4)=AINSS(4)+360.
   28 IF(AINSS(1).LT.0.)29,31
   29 AINSS(1)=AINSS(1)+360.
   31 IF(AINSS(8).LT.0.)32,33
   32 AINSS(8)=AINSS(8)+360.
   33 CONTINUE
      PRINT 103,(AINSS(I),I=1,8)
  103 FORMAT(2X,4HINS=,8(2X,F8.1))
  109 DO 114 I1=1,167
      MTS=NRAD(I1)
      MTS1=MTS.AND.M4
      MTS2=MTS.AND.MC
      NRAD(I1)=MTS1/2+MTS2
      MTS=NRAD(I1)
      NSIGN=MTS.AND.M5
      IF(NSIGN.NE.0)12,13
   12 MTS1=MTS-1
      NRAD(I1)=MTS1.OR.M6
   13 CONTINUE
  114 CONTINUE
      DO 115 J6=1,7
      CHAN(J6)=NRAD(J6)*1.953125
  115 CONTINUE
```

```
      DO 107 I=1,160
      RAD(I)=NRAD(I+7)*VSCALE/51.2
  107 CONTINUE
      RETURN
      END
      SUBROUTINE  PHASE(NTOT,QP)
      COMMON/A/Y,Z
      DIMENSION   Y(8192),Z(8192),ITYPE(2)
      DATA (ITYPE=5HLASER,5HACCEL)
  900 FORMAT (*)  ATEST =*F6.1,*   RTEST =*F6.1,*   STEST =*F7.1,//)
  901 FORMAT (*)     NUMBER OF PHASE SHIFTS FOR *A5,* DATA = *,I4,/,
     * 6X,*MAX PHASE SHIFT = *,F6.2,5X,*MIN PHASE SHIFT = *,F6.2,/,
     * 6X,*DIFFERENCES GREATER THAN RTEST = *,I4/)
      IF(QP - 1).   20,10,30
   10 ATEST = 4.0
      RTEST = 2.4
      STEST = 0.
      UTEST = 32.2
      TTEST = 64.4
      BTEST = 32.2
      GO TO 40
   20 ATEST = 3.5
      RTEST = 2.0
      STEST = 0.
      UTEST = 32.2
      TTEST = 64.4
      BTEST = 32.2
      GO TO 40
   30 ATEST = 5.0
      RTEST = 3.2
      STEST = 0.
      UTEST = 32.2
      TTEST = 64.4
      BTEST = 32.2
   40 PRINT 900,     ATEST,RTEST,STEST
      ICOUNT = 1
      MTOT = NTOT - 1
      NLASPS = NRADPS = NLASDIF = NRADDIF = 0
      RYMAX = RZMAX = 0.
      RYMIN = RZMIN = 1000.
   60 DCY = DCZ = 0.
      DO 160    I = 1,MTOT
      V = Y(I)
      W = Z(I)
      Y(I) = Y(I) + DCY
C
C IF Z = ACCELERATION, NO PHASE SHIFT IS NEEDED AND DCZ = 0.
      DCZ = 0.
C
      Z(I) = Z(I) + DCZ
      AY = Y(I)
      AZ = Z(I)
      BY = Y(I+1) + DCY
      BZ = Z(I+1) + DCZ
      RY = ABSF(AY - BY)
      RZ = ABSF(AZ - BZ)
      SY = AY - RY
      SZ = AZ - RZ
      IF(ICOUNT .EQ. 2)   120,70
   70 IF(RY .LT. ATEST)   80,75
```

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GULF STREAM GROUND TRUTH PROJECT: RESULTS OF NRL AIRBORNE SENSO--ETC(U)
JUN 78 C R MCCLAIN, D T CHEN, D L HAMMOND

UNCLASSIFIED NRL-MR-3779 NL

2 OF 2
AD A057420

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   75 DCY = DCY + QP*(RY/SY)
      NLASPS = NLASPS + 1
      IF(RY .GT. RYMAX)   76,77
   76 RYMAX = RY
      GO TO 80
   77 IF(RY .LT. RYMIN)   78,80
   78 RYMIN = RY
   80 IF(RZ .LT. BTEST)   100,90
   90 DCZ = DCZ + RZ*(RZ/SZ)
      NRADPS = NRADPS + 1
      IF(RZ .GT. RZMAX)   95,100
   95 RZMAX = RZ
      GO TO 160
  100 IF(RZ .LT. RZMIN)   105,160
  105 RZMIN = RZ
      GO TO 160
  120 IF(RY .GT. RTEST  .AND.  RY .LT. STEST)   130,140
  130 DCY = DCY + RY*RY/SY
      NLASDIF = NLASDIF + 1
  140 IF(RZ .GT. UTEST  .AND.  RZ .LT. TTEST)   150,160
  150 DCZ = DCZ + RZ*RZ/SZ
      NRADDIF = NRADDIF + 1
  160 CONTINUE
      Y(NTOT) = Y(NTOT) + DCY
C     Z(NTOT) = Z(NTOT) + DCZ
      IF(ICOUNT .EQ. 2)   200,180
  180 ICOUNT = ICOUNT + 1
      GO TO 60
  200 PRINT 901, ITYPE(1),NLASPS,RYMAX,RYMIN,NLASDIF
      PRINT 901, ITYPE(2),NRADPS,RZMAX,RZMIN,NRADDIF
      RETURN
      END
      SUBROUTINE FOURIER (A,S,M,IFS)
C
C     THIS ROUTINE PERFORMS AN ANALYSIS OF 2**M POINTS BY FIRST DOING
C     AN ANALYSIS OF 2**M/2 COMPLEX POINTS AND THEN ARRANGING THE RESULTS
C
C     A R G U M E N T S
C     1. A - REAL DATA ARRAY - OF DIMENSION 2**M + 2
C     2. S - SIN/COS TABLE - DIMENSION 2**(M-3)
C     3. M - EXPONENT OF 2 - SIZE OF REAL ARRAY
C     4. IFS - -1 FOR FIRST TIME, -2 THEREAFTER
C
      DIMENSION A(1),S(1)
      N = 2**(M-1)
      CALL HARMON(A,S,M-1,IFS,IFERR)
C     MERGE 2 N-POINT ANALYSIS INTO 1 2N-POINT ANALYSIS
      NHALF = N/2
      NTWO = N*2 + 4
      X = XO = COSF(3.1415926536/FLOATF(N))
      Y = YO = SINF(3.1415926536/FLOATF(N))
      DO 1000 K2 = 4,N,2
      K1 = K2 - 1
      N2 = NTWO - K2
      N1 = N2 - 1
      BK1 = A(K1) + A(N1)
      BK2 = A(K2) - A(N2)
      BN1 = A(K2) + A(N2)
      BN2 = A(K1) - A(N1)
      XBN1 = X*BN1
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      XBN2 = X*BN2
      YBN1 = Y*BN1
      YBN2 = Y*BN2
      A(K1) = .5 *(BK1 + XBN1 - YBN2)
      A(K2) = .5 *(-BK2 + XBN2 + YBN1)
      A(N1) = .5 *(BK1 - XBN1 + YBN2)
      A(N2) = .5 *(BK2 + XBN2 + YBN1)
      Q = X*XO - Y*YO
      Y = Y*XO + X*YO
 1000 X = Q
C     COMPLEX E_EMENT A(N)
      A(2*N+1) =(A(1) - A(2))*.5
      A(2*N+2) = 0.0
C     COMPLEX E_EMENT A(0)
      A(1) = .5*(A(1)+A(2))
      A(2) = 0.0
C     COMPLEX E_EMENT A(N/2)
C     A(N+1) = A(N+1)
C     A(N+2) = A(N+2)
      RETURN
      END
      SUBROUTINE HARMON(A,S,M,IFS,IFERR)
      DIMENSION A(1),S(1)
C         HARM, ONE-DIMENSIONAL BASIC FORTRAN VERSION.  J.W.CUOLEY      HARM 001
C     MODIFIED TO RUN ON CDC 3100.
C                                                                       HARM 002
C                                                                       HARM 008
C     DOES EITHER FOURIER SYNTHESIS,I.E.,COMPUTES COMPLEX FOURIER SERIESHARM 009
C     GIVEN A VECTOR OF N COMPLEX FOURIER AMPLITUDES,OR, GIVEN A VECTOR HARM 010
C     OF COMPLEX DATA X DOES FOURIER ANALYSIS, COMPUTING AMPLITUDES.    HARM 011
C     A IS A COMPLEX VECTOR OF LENGTH N=2**M COMPLEX NOS, OR 2*N REAL   HARM 012
C     NUMBERS. A IS TO BE SET BY USER.                                  HARM 013
C     M  IS AN INTEGER 0.LT.M.LE.13, SET BY USER.                       HARM 014
C     S IS A VECTOR S(J)= SIN(2*PI*J/NP ), J=1,2,....,NP/4+1,           HARM 015
C     COMPUTED BY PROGRAM.                                              HARM 016
C     IFS IS A PARAMETER TO BE SET BY USER AS FOLLOWS-                  HARM 017
C     IFS=0 TO SET NP=2**M AND SET UP SINE TABLE S.                     HARM 018
C     IFS=1 TO SET N=NP=2**M, SET UP SIN TABLE, AND DO FOURIER          HARM 019
C     SYNTHESIS, REPLACING THE VECTOR A BY                              HARM 020
C                                                                       HARM 021
C     X(J)= SUM OVER K=0,N-1 OF A(K)*EXP(2*PI*I/N)**(J*K),              HARM 022
C     J=0,N-1, WHERE I=SQRT(-1)                                         HARM 023
C     THE  X#S  ARE STORED WITH  RE X(J) IN CELL  2*J+1                 HARM 024
C     AND  IM X(J)  IN CELL  2*J+2  FOR  J=0,1,2,...,N-1,               HARM 025
C     THE  A#S  ARE STORED IN THE SAME MANNER.                          HARM 026
C                                                                       HARM 027
C     IFS=-1   TO SET  N=NP=2**M,SET UP SIN TABLE, AND DO FOURIER       HARM 028
C     ANALYSIS, TAKING THE INPUT VECTOR A AS X AND                      HARM 029
C     REPLACING IT BY THE A  SATISFYING THE ABOVE FOURIER SERIES,       HARM 030
C     IFS=+2 TO DO FOURIER SYNTHESIS ONLY, WITH A PRE-COMPUTED S,       HARM 031
C     IFS=-2 TO DO FOURIER ANALYSIS ONLY, WITH A PRE-COMPUTED S,        HARM 032
C     IFERR   IS SET BY PROGRAM TO-                                     HARM 033
C     =0 IF NO ERROR DETECTED.                                          HARM 034
C     =1 IF M IS OUT OF RANGE., OR, WHEN IFS=+2,-2, THE                 HARM 035
C     PRE-COMPUTED S TABLE IS NOT LARGE ENOUGH.                         HARM 036
C     =-1 WHEN IFS =+1,-1, MEANS ONE IS RECOMPUTING S TABLE             HARM 037
C     UNNECESSARILY.                                                    HARM 038
C                                                                       HARM 039
C     NOTE- AS STATED ABOVE, THE MAXIMUM VALUE OF M FOR THIS PROGRAM    HARM 040
C     ON THE IBM 7094 IS 13. ON 360 MACHINES HAVING GREATER STORAGE     HARM 041
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C     CAPACITY. ONE SHOULD CHANGE THIS LIMIT BY REPLACING 13 IN          HARM 042
C     STATEMENT 3 BELOW BY LOG2 N, WHERE N IS THE MAX. NO. OF            HARM 043
C     COMPLEX NUMBERS ONE CAN STORE IN HIGH-SPEED CORE.                  HARM 044
C          IF THE CAPACITY OF  HARM  IS TO BE INCREASED, ONE MUST        HARM 045
C     ALSO ADD MORE  DO  STATEMENTS TO THE BINARY SORT ROUTINE           HARM 046
C     FOLLOWING STATEMENT  24  AND CHANGE THE EQUIVALENCE STATEMENTS     HARM 047
C     FOR THE  K#S.                                                      HARM 048
C                                                                        HARM 049
      DIMENSION K(12)
      EQUIVALENCE (K(11),K1),(K(10),K2),(K(9),K3),(K(8),K4),(K(7),K5)
      EQUIVALENCE (K(6),K6),(K(5),K7),(K(4),K8),(K(3),K9),(K(2),K10)
      EQUIVALENCE (K(1),K11),(K(1),N2)
      IF(M)2,2,3                                                         HARM 055
    3 IF(M-11) 5,5,2
    2 IERR=1                                                             HARM 057
    1 RETURN                                                             HARM 058
    5 IERR=0                                                             HARM 059
      N=2**M                                                             HARM 060
      IF(XABSF(IFS) - 1 ) 200,200,10
C     WE ARE DOING TRANSFORM ONLY, SEE IF PRE-COMPUTED                   HARM 062
C     S TABLE IS SUFFICIENTLY LARGE                                      HARM 063
   10 IF( N-NP )20,20,12                                                 HARM 064
   12 IERR=1                                                             HARM 065
      GO TO 200                                                          HARM 066
C     SCRAMBLE A, BY SANDE#S METHOD                                      HARM 067
   20 K(1)=2*N                                                           HARM 068
      DO 22 L=2,M                                                        HARM 069
   22 K(L)=K(L-1)/2                                                      HARM 070
      DO 24 L=M,10
   24 K(L+1)=2                                                           HARM 072
C     NOTE EQUIVALENCE OF KL AND K(14-L)                                 HARM 073
C     BINARY SORT-                                                       HARM 074
      IJ=2                                                               HARM 075
      J1=2
   25 DO 30 J2=J1,K2,K1
      DO 30 J3=J2,K3,K2                                                  HARM 078
      DO 30 J4=J3,K4,K3                                                  HARM 079
      DO 30 J5=J4,K5,K4                                                  HARM 080
      DO 30 J6=J5,K6,K5                                                  HARM 081
      DO 30 J7=J6,K7,K6                                                  HARM 082
      DO 30 J8=J7,K8,K7                                                  HARM 083
      DO 30 J9=J8,K9,K8                                                  HARM 084
      DO 30 J10=J9,K10,K9                                                HARM 085
      DO 30 JI=J10,K11,K10
      IF(IJ-JI)28,30,30                                                  HARM 089
   28 T=A(IJ-1 )                                                         HARM 090
      A(IJ-1)=A(JI-1)                                                    HARM 091
      A(JI-1)=T                                                          HARM 092
      T=A(IJ)                                                            HARM 093
      A(IJ)=A(JI)                                                        HARM 094
      A(JI)=T                                                            HARM 095
   30 IJ=IJ+2                                                            HARM 096
      J1=J1+2
      IF(K1-J1)31,25,25
   31 IF(IFS)32,2,36                                                     HARM 097
C     DOING FOURIER ANALYSIS,SO DIV. BY N AND CONJUGATE.                 HARM 098
   32 FN = FLOATF(N)
      DO 34 I=1,N                                                        HARM 100
      A(2*I-1) = A(2*I-1)/FN                                             HARM 101
   34 A(2*I)=-A(2*I)/FN                                                  HARM 102
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C       SPECIAL CASE- L=1                                                HARM 103
   36   DO 40 I=1,N,2                                                    HARM 104
        T = A(2*I-1)                                                     HARM 105
        A(2*I-1) =T + A(2*I+1)                                           HARM 106
        A(2*I+1)=T-A(2*I+1)                                              HARM 107
        T=A(2*I)                                                         HARM 108
        A(2*I) = T + A(2*I+2)                                            HARM 109
   40   A(2*I+2)= T - A(2*I+2)                                           HARM 110
        IF(M-1) 2,1   ,50                                                HARM 111
C       SET FOR L=2                                                      HARM 112
   50   LEXP1=2                                                          HARM 113
C       LEXP1=2**(L-1)                                                   HARM 114
        LEXP=8                                                           HARM 115
C       LEXP=2**(_*1)                                                    HARM 116
        NPL= 2**MT                                                       HARM 117
C       NPL = NP* 2**-L                                                  HARM 118
        DO 130 L=2,M                                                     HARM 119
C       SPECIAL CASE- J=0                                                HARM 120
        DO 60 I=2,N2,LEXP                                                HARM 121
        I1=I + LEXP1                                                     HARM 122
        I2=I1+ LEXP1                                                     HARM 123
        I3 =I2+LEXP1                                                     HARM 124
        T=A(I-1)                                                         HARM 125
        A(I-1) = T +A(I2-1)                                              HARM 126
        A(I2-1) = T-A(I2-1)                                              HARM 127
        T =A(I)                                                          HARM 128
        A(I) = T+A(I2)                                                   HARM 129
        A(I2) = T-A(I2)                                                  HARM 130
        T= -A(I3)                                                        HARM 131
        TI = A(I3+1)                                                     HARM 132
        A(I3-1) = A(I1-1) - T                                            HARM 133
        A(I3   ) = A(I1  )   - TI                                        HARM 134
        A(I1-1) = A(I1-1) +T                                             HARM 135
   60   A(I1)   = A(I1   )  +TI                                          HARM 136
        IF(L-2) 120,120,90                                               HARM 137
   90   KLAST=N2-_EXP                                                    HARM 138
        JJ=NPL                                                           HARM 139
        DO 110 J=4,LEXP1,2                                               HARM 140
        NPJJ=NT-JJ                                                       HARM 141
        UR=S(NPJJ)                                                       HARM 142
        UI=S(JJ)                                                         HARM 143
        ILAST=J+K_AST                                                    HARM 144
        DO 100 I= J,ILAST,LEXP                                           HARM 145
        I1=I+LEXP1                                                       HARM 146
        I2=I1+LEXP1                                                      HARM 147
        I3=I2+LEXP1                                                      HARM 148
        T=A(I2-1)*UR-A(I2)*UI                                            HARM 149
        TI=A(I2-1)*UI+A(I2)*UR                                           HARM 150
        A(I2-1)=A(I-1)-T                                                 HARM 151
        A(I2   )=A(I   ) - TI                                            HARM 152
        A(I-1) =A(I-1)+T                                                 HARM 153
        A(I)   =A(I)+TI                                                  HARM 154
        T=-A(I3-1)*UI-A(I3)*UR                                           HARM 155
        TI=A(I3-1)*UR-A(I3)*UI                                           HARM 156
        A(I3-1)=A(I1-1)-T                                                B1RM 157
        A(I3)   =A(I1  )-TI                                              HARM 158
        A(I1-1)=A(I1-1)+T                                                HARM 159
  100   A(I1)   =A(I1)   +TI                                             HARM 160
C       END OF I _OOP                                                    HARM 161
  110   JJ=JJ+NPL                                                        HARM 162
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C       END OF J LOOP                                                   HARM 163
  120   LEXP1=2*LEXP1                                                  HARM 164
        LEXP = 2*LEXP                                                   HARM 165
  130   NPL=NPL/2                                                       HARM 166
C       END OF L LOOP                                                   HARM 167
        IF(IFS)145,2,1
CC      DOING FOURIER ANALYSIS. REPLACE A BY CONJUGATE.                 HARM 169
  145   DO 150 I=1,N                                                    HARM 170
  150   A(2*I) =-A(2*I)
        GO TO 1
C       RETURN                                                          HARM 173
C       MAKE TABLE OF S(J)=SIN(2*PI*J/NP),J=1,2,...,NT-1,NT=NP/4        HARM 174
  200   NP=N                                                            HARM 175
        MP=M                                                            HARM 176
        NT=N/4                                                          HARM 177
        MT=M-2                                                          HARM 178
        IF(MT) 260,260,205                                              HARM 179
  205   THETA=.7853981634                                               HARM 180
C       THETA=PI/2**(L+1)     FOR L=1                                   HARM 181
        JSTEP = NT
C       JSTEP = 2**( MT-L+1 ) FOR L=1                                   HARM 183
        JDIF = NT/2                                                     HARM 184
C       JDIF = 2**(MT-L)  FOR L=1                                       HARM 185
        S(JDIF) = SINF(THETA)
        IF (MT-2)260,220,220                                            HARM 187
  220   DO 250 L=2,MT                                                   HARM 188
        THETA = THETA/2.                                                HARM 189
        JSTEP2 = JSTEP                                                  HARM 190
        JSTEP = JDIF                                                    HARM 191
        JDIF = JDIF/2                                                   HARM 192
        S(JDIF)=SINF(THETA)
        JC1=NT-JDIF                                                     HARM 194
        S(JC1) =COSF(THETA)
        JLAST=NT-JSTEP2                                                 HARM 196
        IF(JLAST-JSTEP)250,230,230                                      HARM 197
  230   DO 240 J=JSTEP,JLAST,JSTEP                                      HARM 198
        JC=NT-J                                                         HARM 199
        JD=J+JDIF                                                       HARM 200
  240   S(JD)=S(J)+S(JC1)+S(JDIF)+S(JC)                                 HARM 201
  250   CONTINUE                                                        HARM 202
  260   IF(IFS)20,1,20                                                  HARM 203
        END
           SCOPE
W=  00  LOAD
W=  00  RUN,200,60000
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